FEEDBACK

* Two kinds of feedback:-
  (i) negative or degenerative.
  (ii) positive or regenerative.

* Types of amplifiers:-
  (i) Voltage-in → Voltage-out ⇒ A_v.
  (ii) Current-in → Current-out ⇒ A_i.
  (iii) Voltage-in → Current-out ⇒ G_m
  (iv) Current-in → Voltage-out ⇒ R_m.

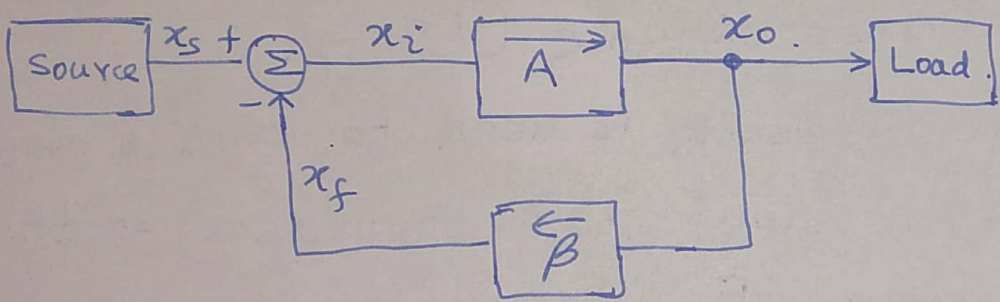
* A_v = Voltage gain (dimensionless)
* A_i = Current gain (dimensionless)
* G_m = Transconductance (Siemens or Mhos)
* R_m = Transresistance (Ohms).

* Negative-Feedback is used to realize amplifiers (any of the above four topologies) so that the following properties are achieved:-
  (i) Gain Desensitization ⇒ make sure that the gain is not sensitive to process, voltage, and temperature (PVT)
  (ii) Non-linearity Reduction ⇒ Make the output linearly proportional to input.
  (iii) Improvement in Input and Output impedances.
  (iv) Enhance the bandwidth.
  (v) Reduce the effect of noise ⇒ Not discussed & is little subtle.

* **Positive Feedback** is used to
  - ⇒ realize oscillators which serve as clock sources.
  - ⇒ realize regenerative amplifiers used in latches and sense-amplifiers and find extensive application in Memories and digital sequential circuits.

NOTE:- All the goodies of negative-feedback come at the expense of reduction in gain. (No free lunch).
☹ !?!

GENERAL FEEDBACK STRUCTURE:-



Signal-flow diagram

A = open-loop amplifier gain (i.e., A_v, A_i, G_m, or R_m)

β = feedback factor.

Now, $x_o = A x_i$, $x_f = \beta x_o$, and $x_i = x_s - x_f$.

Thus,

$$A_f = \frac{x_o}{x_s} = \frac{A}{1 + A\beta}.$$

$A\beta$ = Loop-gain.

If, $A\beta >> 1$, then, $A_f = \frac{1}{\beta}$. ⇒ gain is determined by feedback networ

A_f = Closed Loop Gain.

* If β is realized using passive circuit then it does not vary with P.V.T significantly resulting in stable gain.

Properties of Negative Feedback.

① Gain Desensitization :-

$$A_f = \frac{A}{1+A\beta}.$$

If A changes by 20% then A_f changes by 0.025%.

$$\frac{dA_f}{A_f} = \frac{1}{1+A\beta} \frac{dA}{A}.$$

$(1+A\beta)$ is called desensitivity factor.

② Bandwidth Extension :-

Let, $$A(s) = \frac{A_M}{1+ s/\omega_H}.$$

where, ω_H is the upper 3-dB cut-off frequency.

Thus, $$A_f(s) = \frac{A(s)}{1+\beta A(s)}$$ .... where β is assumed to be frequency independent.

$$\Rightarrow A_f(s) = \frac{A_M/(1+A_M\beta)}{1+\frac{s}{\omega_H(1+A_M\beta)}}$$

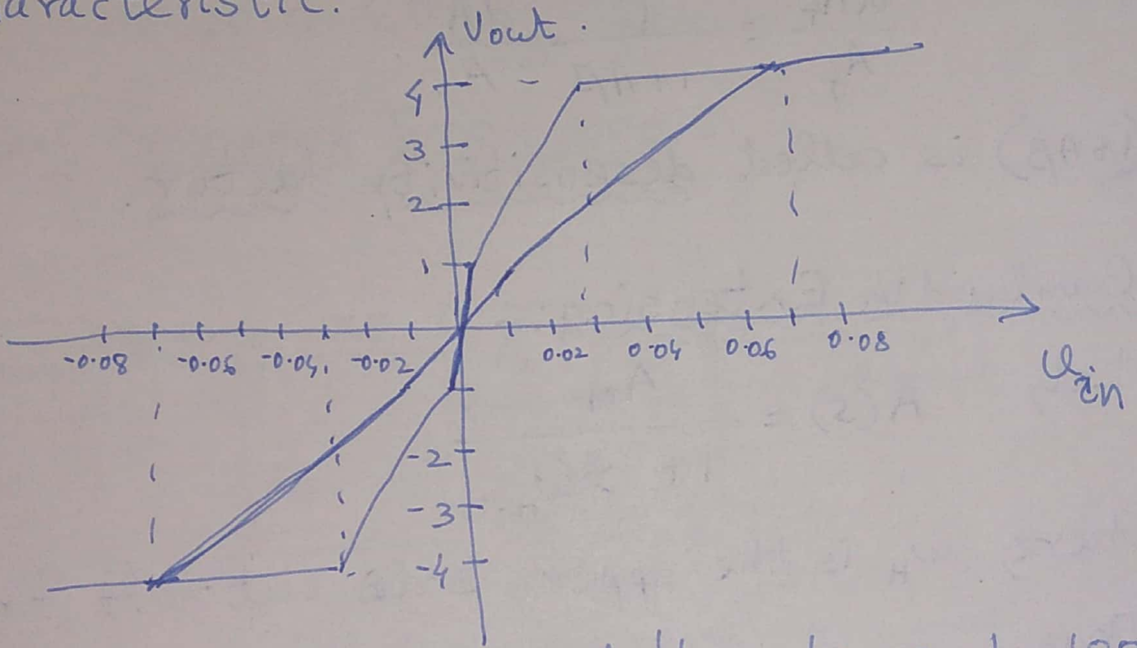
$$\Rightarrow \omega_{Hf} = (1+A_M\beta)\,\omega_H.$$

④ If the open-loop amplifier has lower 3-dB cut off frequency of ω_L. then after feedback we get,

$$\omega_{Lf} = \frac{\omega_L}{(1+A_M\beta)}$$

*Since we assumed a single-pole system the gain-bandwidth product is maintained constant.

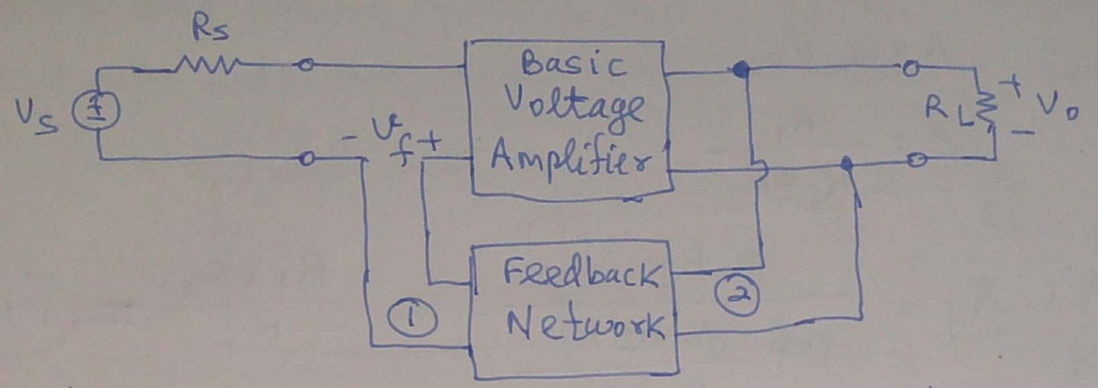
③ Reduction in Non-Linear Distortion:- Negative feedback significantly linearizes the input-output characteristic.



A = 1000 in beginning and then changes to 100. If $\beta = 0.01$ then the closed loop gain varies from 90.9 to 50.

④ Enhancement of Input-Output Impedances:- To be discussed for various topologies of feedback.

VOLTAGE AMPLIFIER :-



⇒ Voltage-Mixing at input & voltage-sampling in the output.

⇒ Series - Shunt.

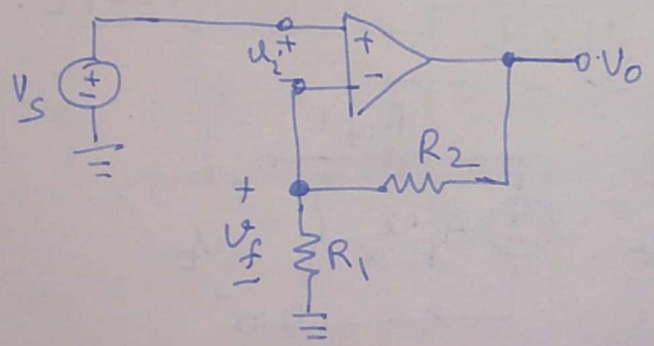
* So feedback topology will have some mixing in the input and some sampling at output.

* Voltage mixing ⇒ series.
  Current mixing ⇒ shunt.

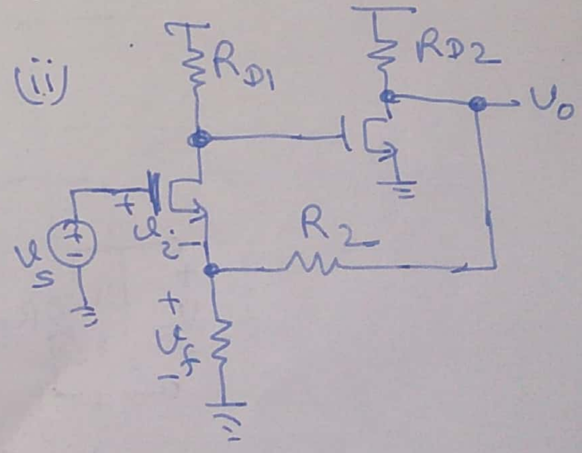
* Voltage Sampling ⇒ shunt.
  Current sampling ⇒ series.

Examples :-

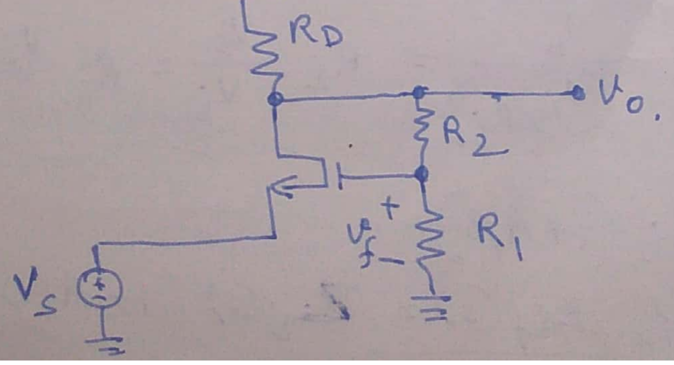
(i)



(ii)



(iii)



⑥ In. example (iii) if $(R_1+R_2) \gg R_D$

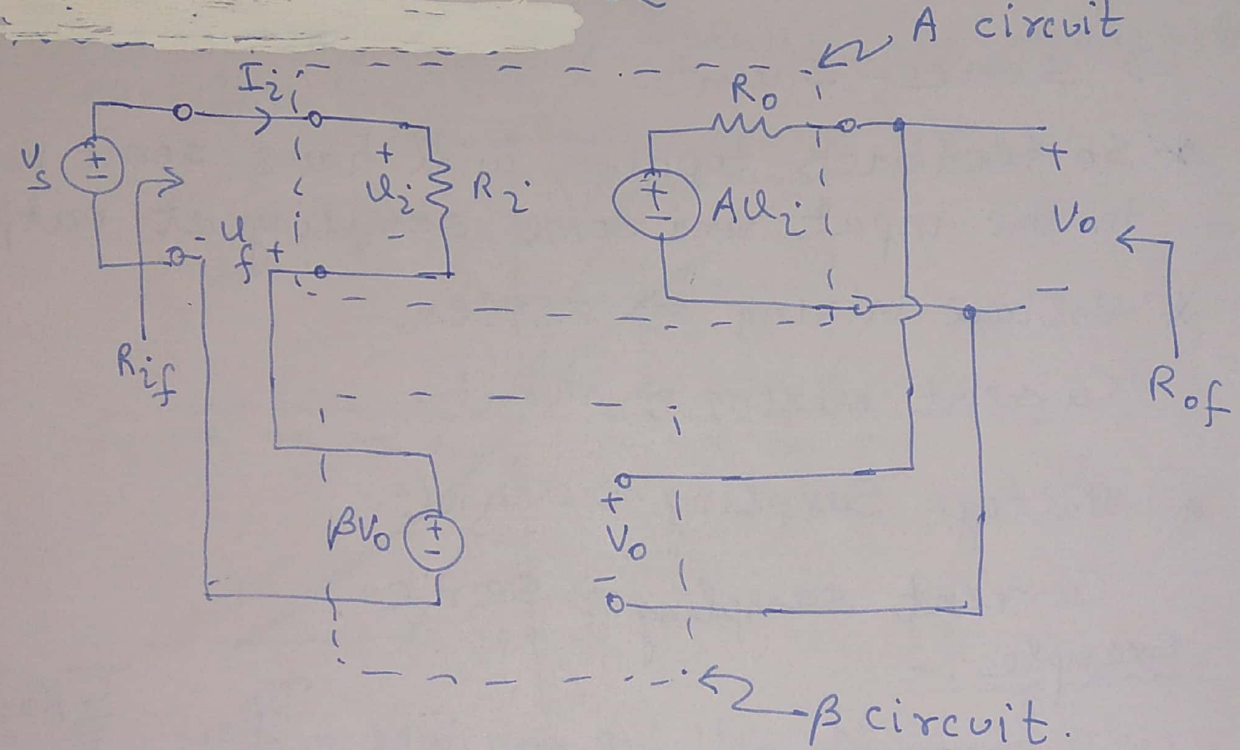
$$A = g_m R_D.$$

$$\beta = \frac{R_1}{R_1+R_2}.$$

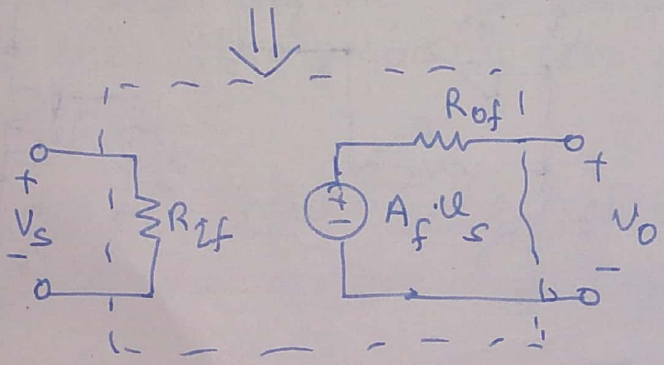
$$\therefore\ A_f = \frac{g_m R_D}{1+\frac{g_m \cdot R_D R_1}{R_1+R_2}} \approx \frac{R_1+R_2}{R_1} \approx \left(1+\frac{R_2}{R_1}\right)$$

if, $A\beta >> 1$.

CALCULATION OF I/O IMPEDANCES:-



⇓

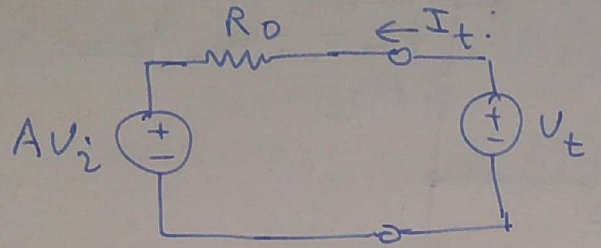


Now, $$R_{if} = \frac{V_s}{I_i} = \frac{V_s}{(V_i/R_i)} = R_i\,\frac{V_s}{V_i} = R_i\,\frac{V_i+\beta A V_i}{V_i}$$

$$\Rightarrow R_{if} = R_i\,(1+A\beta).$$

Generaized impedance, $Z_{if}(s) = Z_i(s)\,\left(1+A(s)\beta(s)\right).$

In order to compute R_{of} apply V_t at the output port and short V_s. ie., make $V_s = 0$. Thus, at the output side we will have something like this,



$$R_{of} = \frac{V_t}{I_t}.$$

$$\Rightarrow I_t = \frac{V_t - AV_i}{R_o}.$$

Since, $V_s = 0 \Rightarrow V_i = -\beta V_o = -\beta V_t$, resulting in

$$I_t = \frac{V_t + A\beta V_t}{R_o}.$$

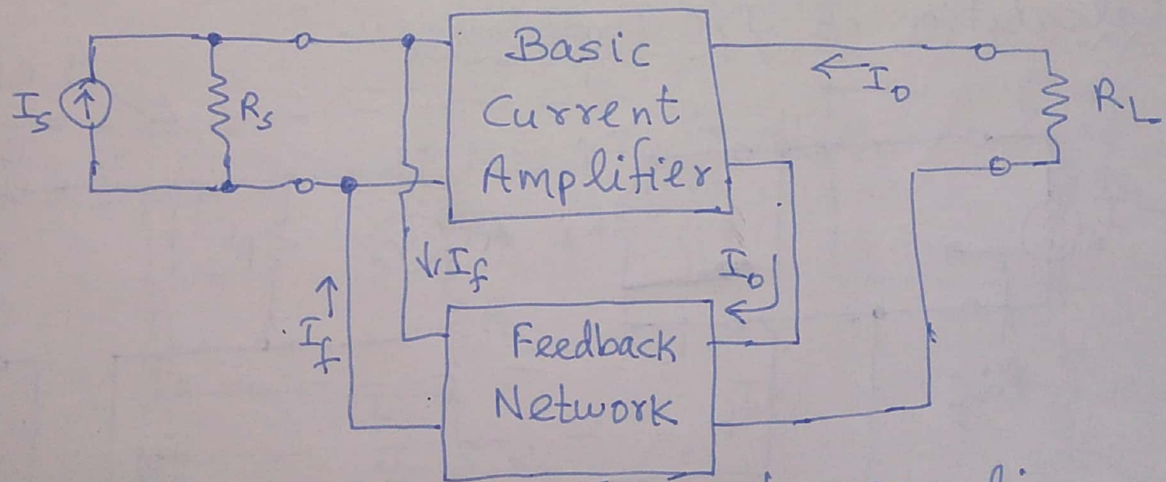
$$\Rightarrow \frac{V_t}{I_t} = \frac{R_o}{1 + A\beta}.$$

$$\Rightarrow R_{of} = \frac{R_o}{1 + A\beta}$$

which can be generalized to,

$$Z_{of}(s) = \frac{Z_o(s)}{1 + A(s)\beta(s)}.$$

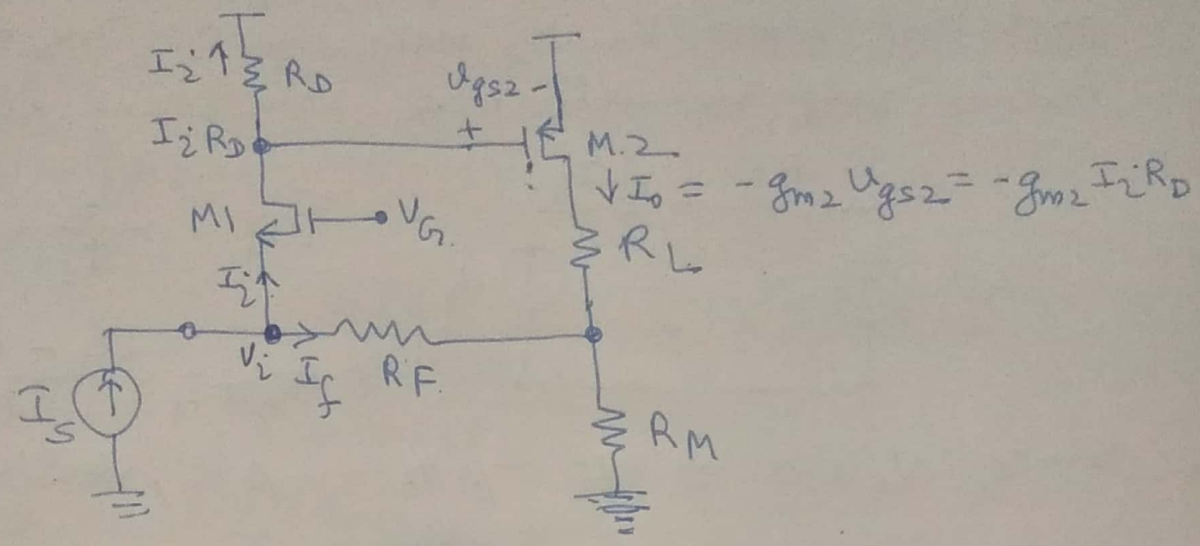
CURRENT AMPLIFIERS:-



* $\underbrace{\text{Current-mixing}}_{\text{shunt}}$ & $\underbrace{\text{Current-sampling}}_{\text{series}}$.

shunt-series feedback.

⑧ Example :-



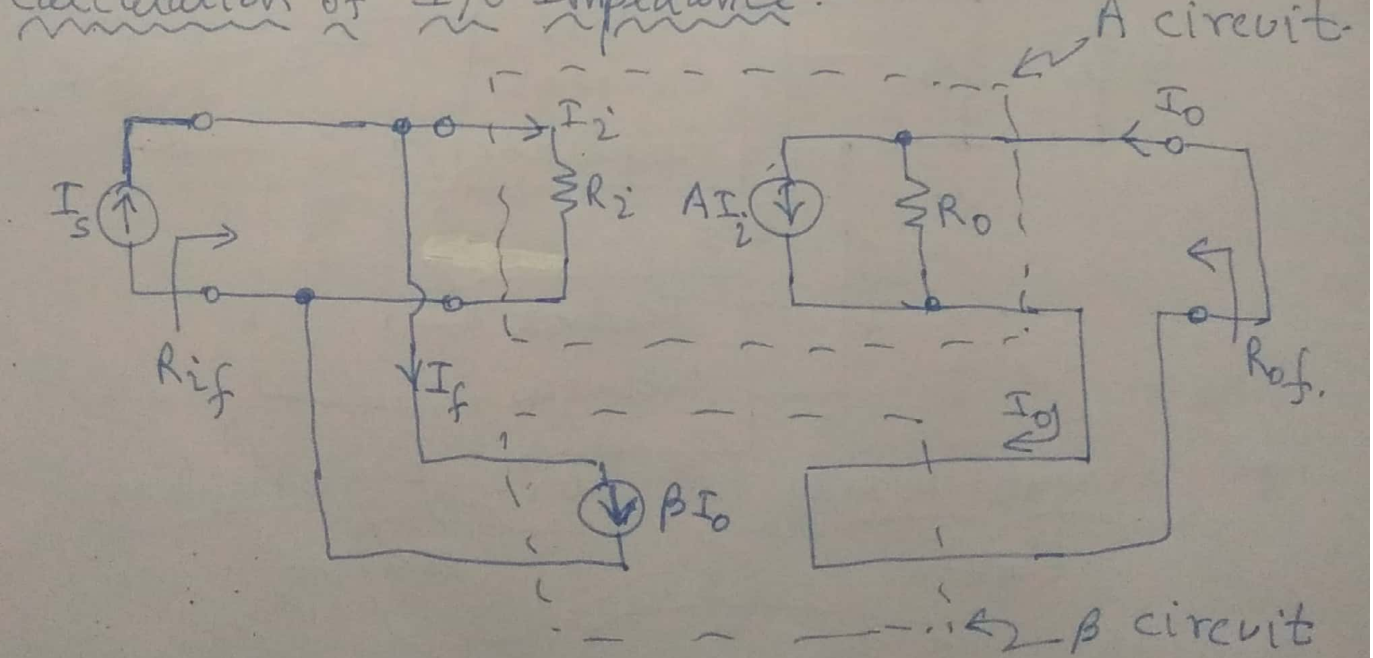
* Impedance seen at source of Q_1 is very small
$\Rightarrow$ v_i is very small and hence can be considered "0". to compute I_f. Thus,

$$\beta = \frac{I_f}{I_o} \cong -\frac{R_M}{R_F + R_M}.$$

Here, $A = \frac{I_o}{I_i} = -g_{m2} R_D$. resulting in,

$$\frac{I_o}{I_s} = A_f = -\frac{g_{m2} R_D}{1 + g_{m2} R_D / \left(1 + \frac{R_F}{R_M}\right)}$$

Calculation of I/O Impedance :-



9

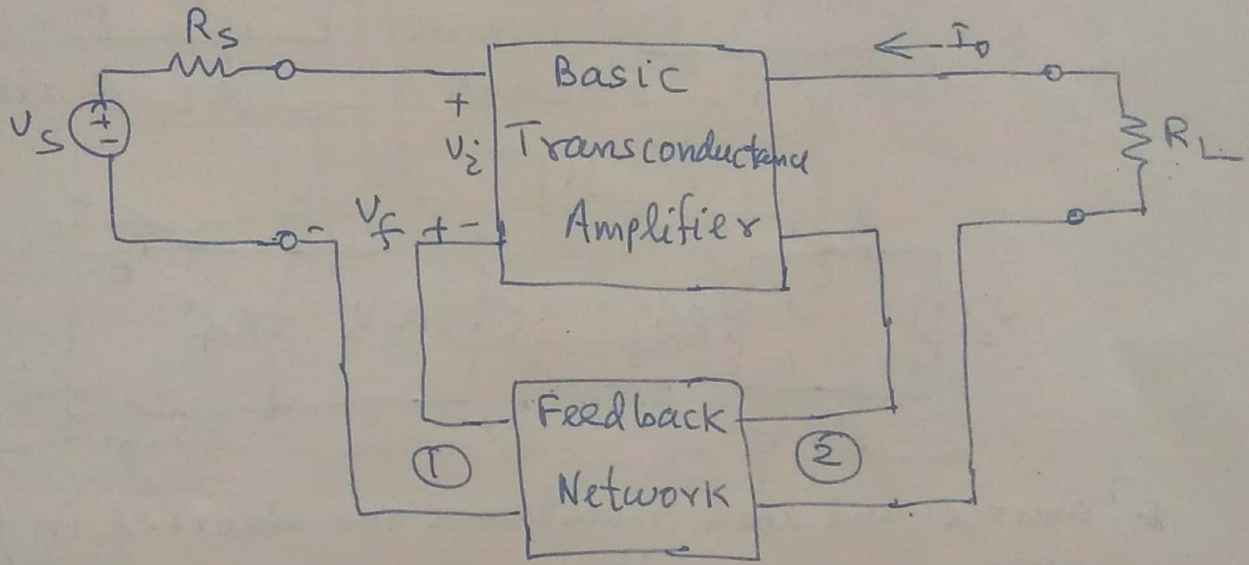
$$A_f = \frac{I_o}{I_s} = \frac{A}{1+A\beta}$$

and hence, $R_{if} = \dfrac{R_i}{1+A\beta}$

and $R_{of} = R_o(1+A\beta)$.

* Source & load resistances have been absorbed in A-circuit.
* β network does not load the A-circuit $\Rightarrow$ it samples the short-circuit current.
*

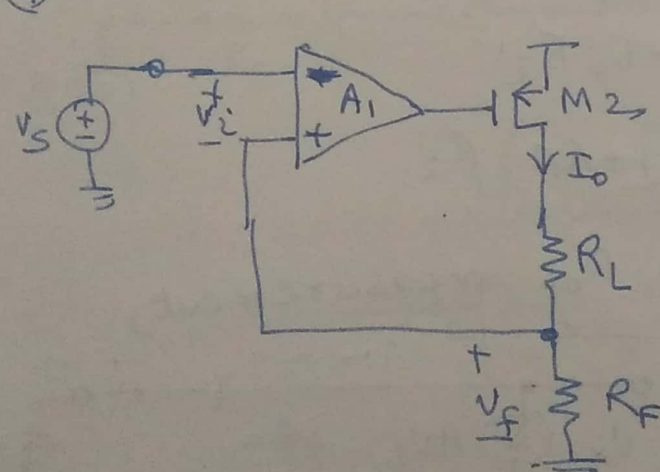
TRANSCONDUCTANCE AMPLIFIER :-



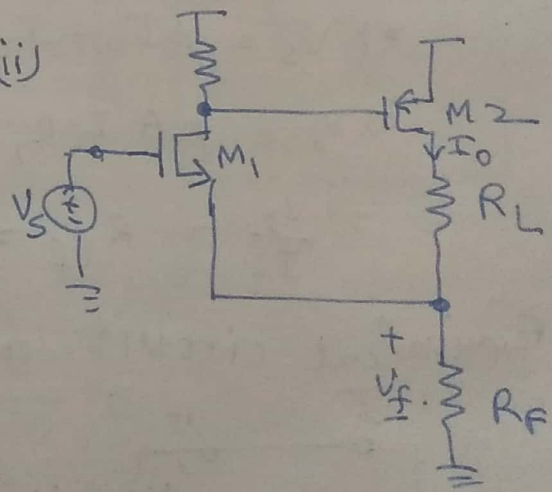
* $\underbrace{\text{Voltage-Mixing}}_{\text{series}}$ & $\underbrace{\text{Current sampling}}_{\text{series.}}$

Example :-

(i)



(ii)

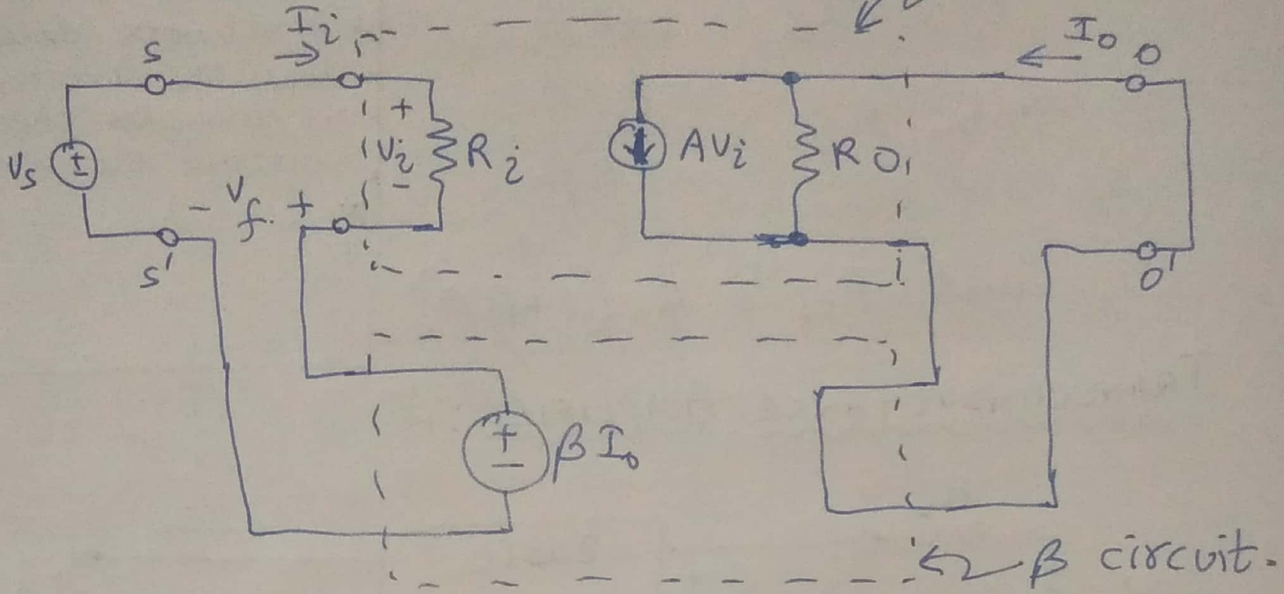


Here, $\dfrac{I_o}{V_i} = g_{m2}A_1$.

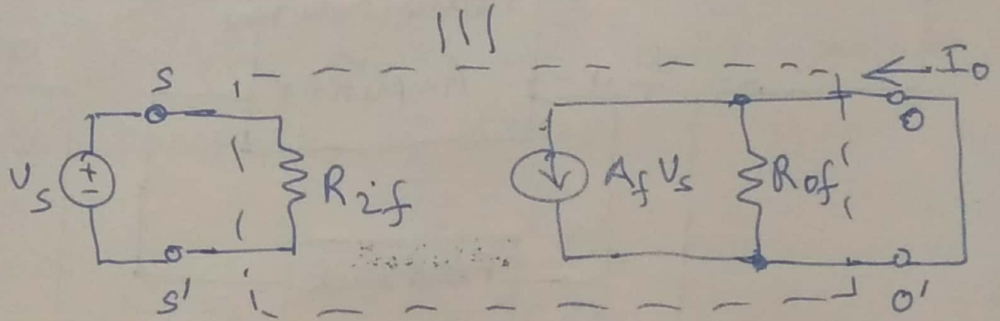
$\beta = R_F$

and $A_f = \dfrac{I_o}{V_s} = \dfrac{A_1 g_{m2}}{1+A_1 g_{m2} R_F} \simeq \dfrac{1}{R_F}$.

COMPUTE THE I/O IMPEDANCE:-



≡



* source and load resistances are absorbed in the ~~source~~ A-circuit.

* A_f is short circuit transconductance.

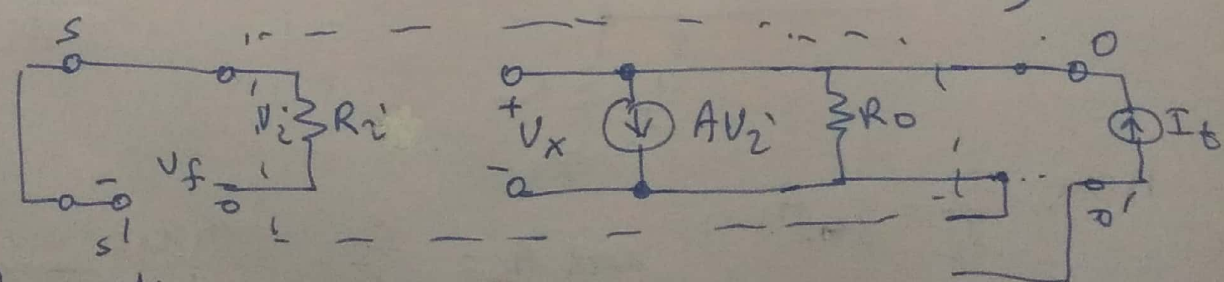
Now, $V_s = V_f + V_i$

$\Rightarrow V_s = \beta I_o + I_i R_i$

$\Rightarrow V_s = \beta A I_i R_i + I_i R_i$

$\Rightarrow \frac{V_s}{I_i} = R_{if} = (1 + A\beta) R_i$

Equivalent circuit for R_{of} measurement,



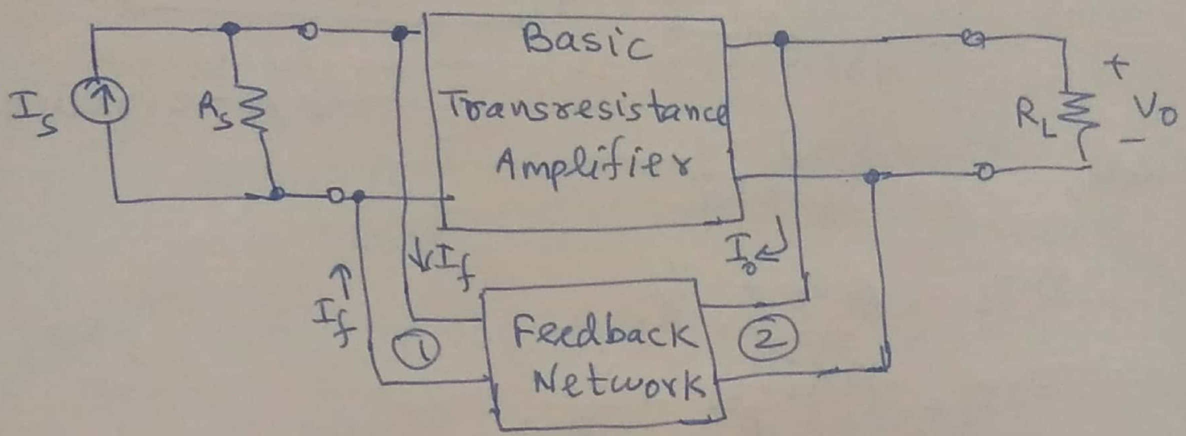
Now, $R_{of} = \frac{V_x}{I_t}$.

Here, $v_i = -v_f = -\beta I_o = \beta I_i$. Thus,

$$V_x = (I_t - A v_i) R_o = I_t (1 + A\beta) R_o .$$

$$\Rightarrow \frac{V_x}{I_t} = R_o (1 + A\beta) .$$

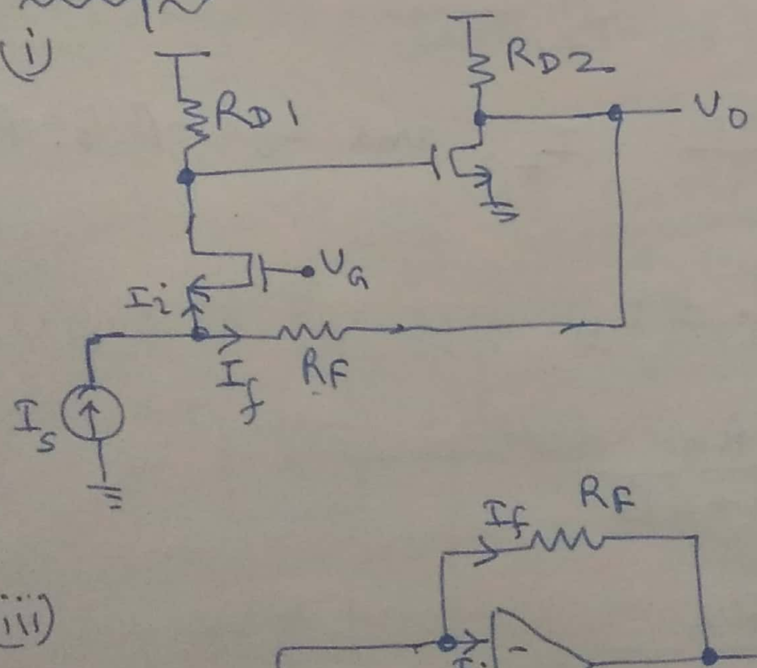
TRANSRESISTANCE AMPLIFIER :-



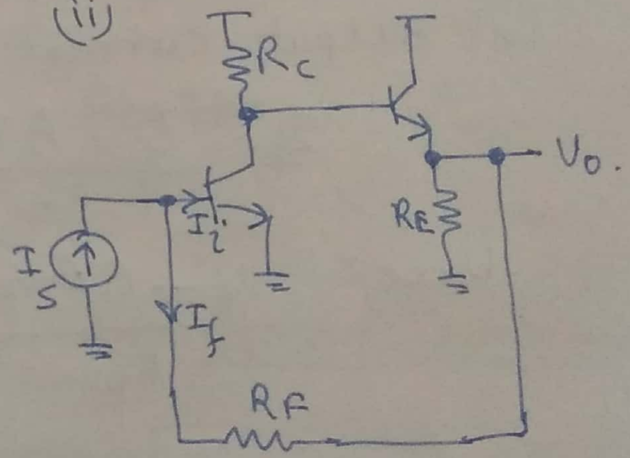
* $\underbrace{\text{Current-mixing}}_{\text{shunt}}$ & $\underbrace{\text{VOLTAGE sampling}}_{\text{shunt}}$.

Example :-

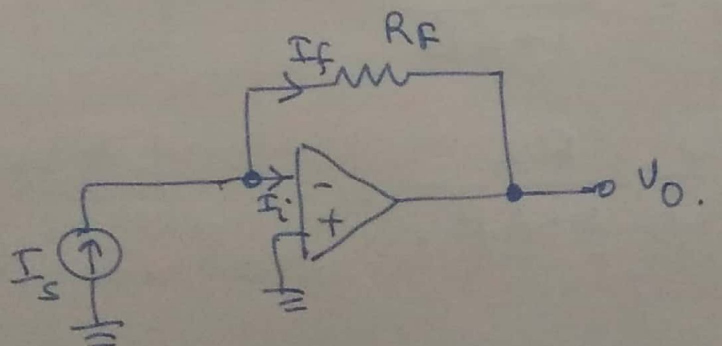
(i)



(ii)

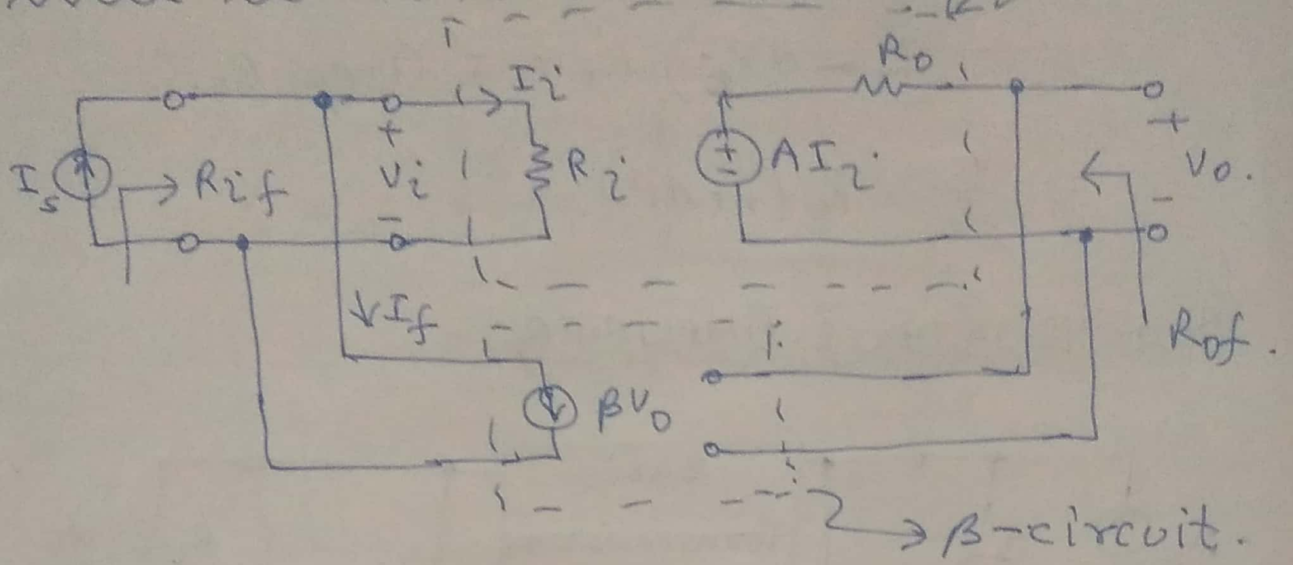


(iii)



(12)

Compute I/O Impedance:-



Note, $I_s = I_f + I_i$

$$\Rightarrow I_s = \beta V_o + \frac{V_i}{R_i}$$

$$\Rightarrow I_s = \frac{\beta A_i V_i}{R_i} + \frac{V_i}{R_i}$$

$$\Rightarrow \frac{V_i}{I_s} = \frac{R_i}{1+A\beta} := R_{if}.$$

To compute R_{of} open I_s and apply V_t at output. Let output current be I_t. Thus,

$$\frac{V_t - AI_i}{R_o} = I_t \quad \text{and } I_i = -\beta V_o = -\beta V_t.$$

Hence, $$\frac{V_t + A\beta V_t}{R_o} = I_t.$$

$$\Rightarrow \frac{V_t}{I_t} = \frac{R_o}{1+A\beta}$$

$$\Rightarrow R_{of} = \frac{R_o}{1+A\beta}.$$

SUMMARY:-

* VOLTAGE AMPLIFIER :-

⇒ series - shunt feedback.

⇒ $\underbrace{\text{Voltage}}_{\text{sense}}$ - $\underbrace{\text{voltage}}_{\text{return}}$ feedback.

* Current AMPLIFIER :-

⇒ shunt-series feedback

⇒ $\underbrace{\text{current}}_{\text{sense}}$ - $\underbrace{\text{current}}_{\text{return}}$ feedback.

* TRANSCONDUCTANCE AMPLIFIER :-

⇒ series - series feedback

⇒ $\underbrace{\text{current}}_{\text{sense}}$ - $\underbrace{\text{voltage}}_{\text{return}}$ feedback.

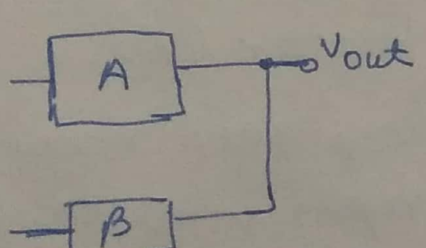
* TRANSRESISTANCE AMPLIFIER :-

⇒ shunt - shunt feedback.

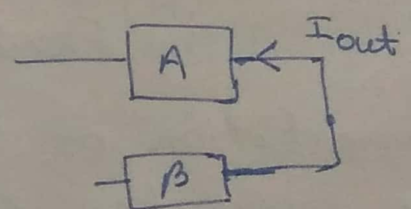
⇒ $\underbrace{\text{voltage}}_{\text{sense}}$ - $\underbrace{\text{current}}_{\text{return}}$ feedback

EFFECT OF FEEDBACK ON INPUT AND OUTPUT IMPEDANCE

SENSE

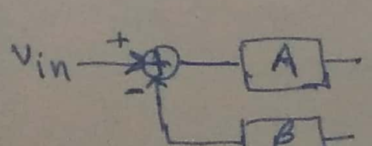


Output Impedance falls by (1 + Loop Gain)

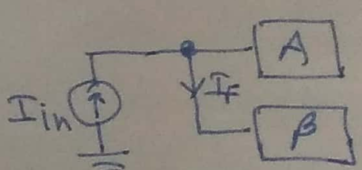


Output Impedance rises by (1+ loop gain).

RETURN



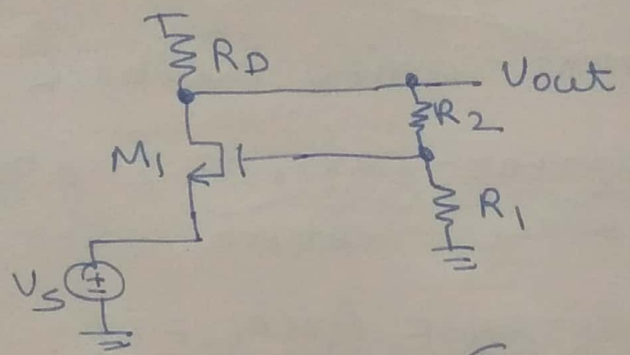
Input Impedance rises by (1+ loop gain)



Input Impedance falls by (1+ loop gain)

(14) LOADING EFFECT :-

* TILL now we have assumed that the I/O impedance of feedback-network does not affect the forward amplifier.
* However this is not the case.
* For example in the following figure :-



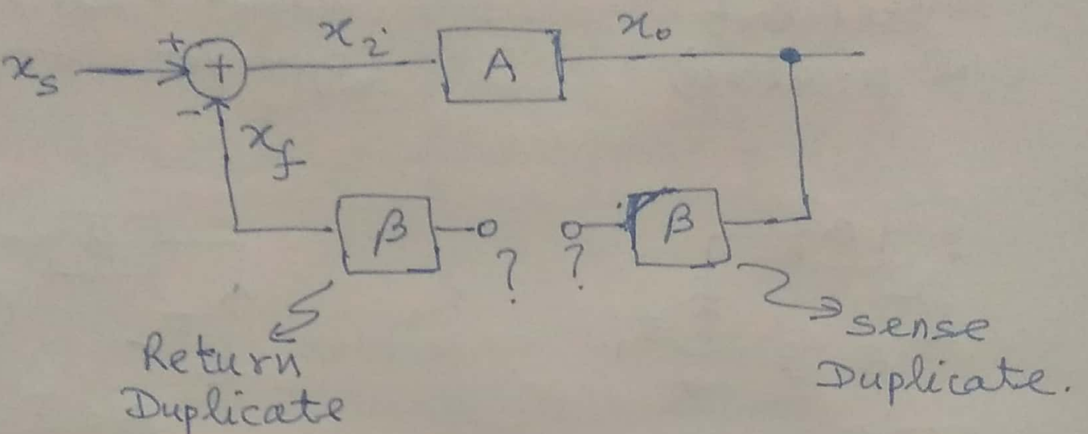
we have assumed that $(R_2+R_1) >> R_D$ so as to not load the forward amplifier comprising of M_1 and R_D.

If $(R_2+R_1) \not\gg R_D$ then the gain of the forward amplifier will reduce. from $g_{m1}R_D$ to $g_{m1}[R_D \| (R_1+R_2)]$

* Computation of the closed-loop gain requires that we compute the following things :-
  (i) Open-loop gain (A)
  (ii) Feedback-factor (β).
* Computation of open-loop gain requires that we break the loop properly ⇒ taking the loading effect into account. break the loops

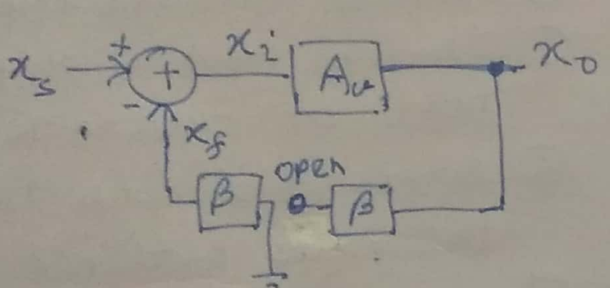
RULES FOR BREAKING THE LOOP:- We will illustrate ~~thing~~ this using signal-flow graph.

* The loop is broken by duplicating the feedback network at both the input and the output of the overall system as shown below:-

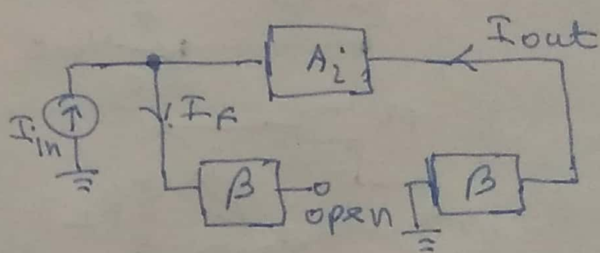


* But, what do you do with the output port of β-network in the sense duplicate and the input port of the β-network in the return duplicate.

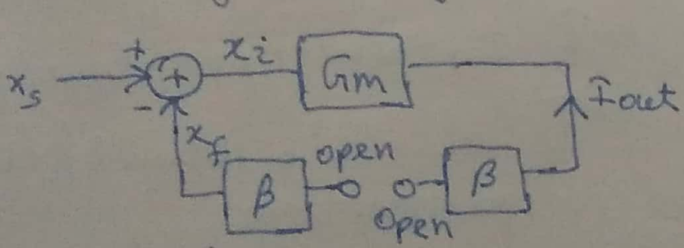
This depends on kind of feedback.



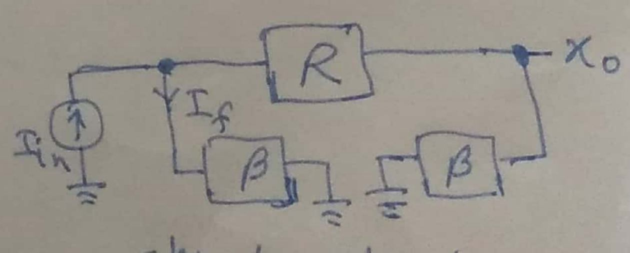
series-shunt
(voltage-voltage)



shunt-series
(current-current).

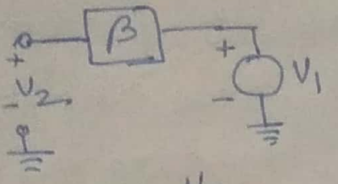


series-series
(current-voltage)



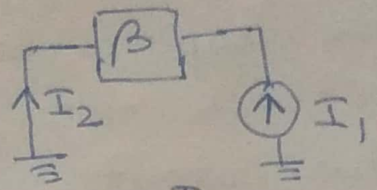
shunt-shunt
(voltage-current)

COMPUTATION OF FEEDBACK FACTOR (β):-



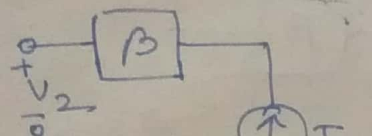
$$\beta = \frac{V_2}{V_1}$$

series-shunt
(voltage-voltage)



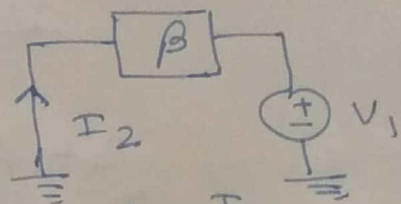
$$\beta = \frac{I_2}{I_1}$$

shunt - series
(current-current)



$$\beta = \frac{V_2}{I_1}$$

series-series
(current-voltage)

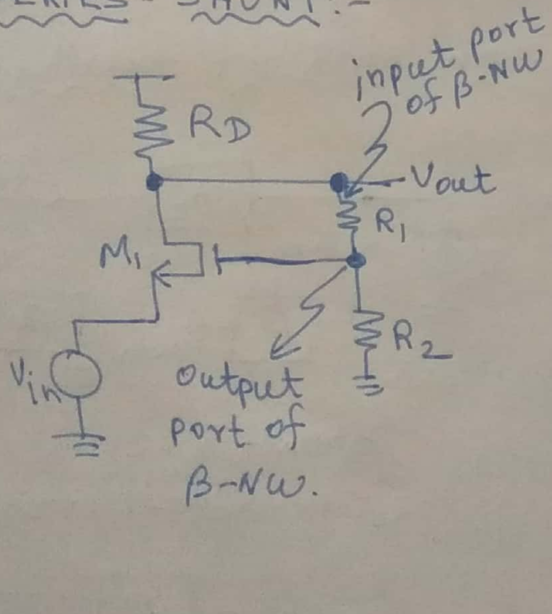


$$\beta = \frac{I_2}{V_1}$$

shunt-shunt
(voltage-current).

Examples:-

① SERIES-SHUNT:-



steps:-

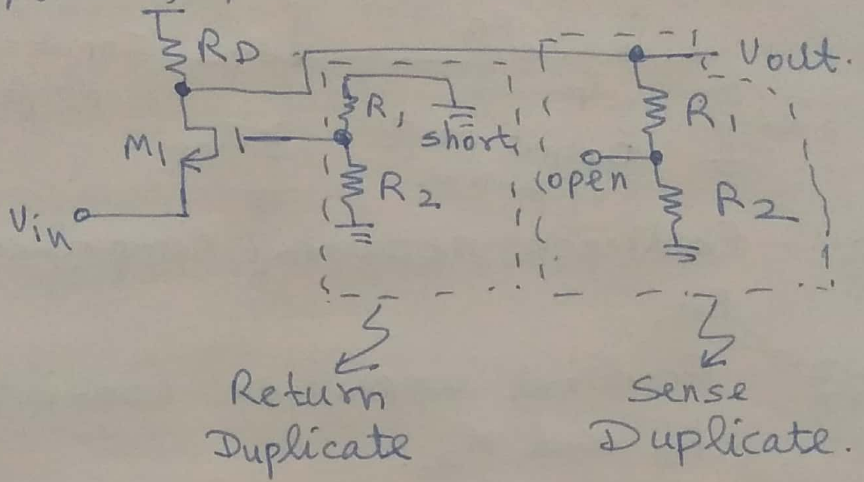
① Identify feedback network.
② Identify forward amplifier.
③ Identify input & output port of feedback network.
④ Break the loop following the rules outlined earlier.
⑤ obtain β following the rules given earlier.
⑥ Obtain open-loop gain
⑦ Calculate closed-loop parameters.

step-1 :- Feedback-network comprises of R_1 and R_2.

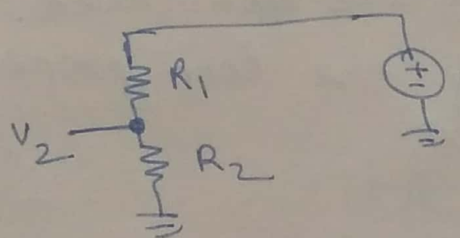
step-2 :- Ideal forward amplifier comprises of M_1 and R_D.

step-3 :- I/O port of β-network is annotated.

step-4 :- Breaking the loop properly, i.e. at output port of β-NW.



step-5 :- obtaining β.



$$\Rightarrow \beta = \frac{R_2}{R_1+R_2}$$

step-6 :- Open-loop gain, $A_v = g_{m1}\left[R_D \parallel (R_1+R_2)\right]$.

step-7 :-

$$A_{v,\text{closed}} = \frac{g_{m1}\left[R_D \parallel (R_1+R_2)\right]}{1+\frac{R_2}{R_1+R_2}\, g_{m1}\left[R_D \parallel (R_1+R_2)\right]}$$

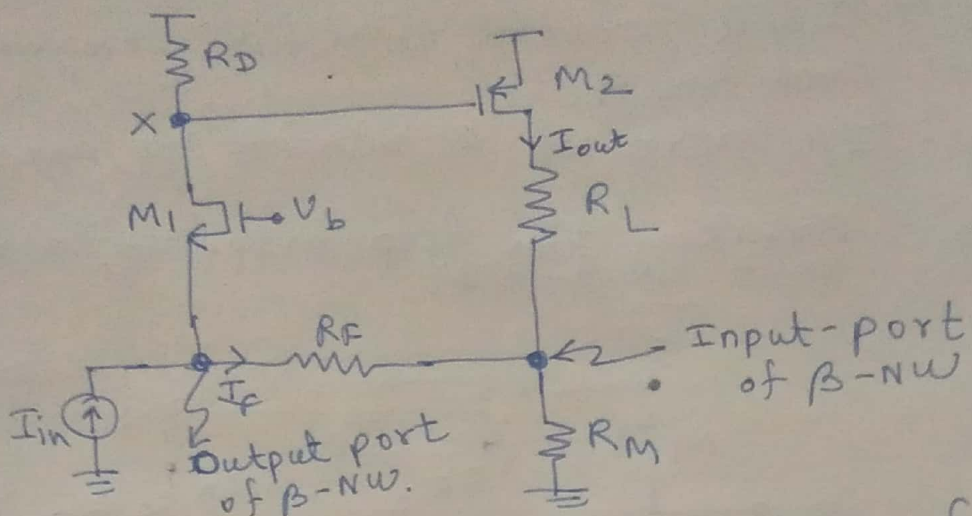
$$R_{in,open} = 1/g_{m1} \quad \cdots \left[\lambda = 0\right]$$

$$R_{out,open} = R_D \parallel (R_1+R_2) \quad \cdots \left[\lambda = 0\right]$$

$$\therefore R_{in,closed} = \frac{1}{g_{m1}}\left[1+\frac{R_2}{R_1+R_2}\, g_{m1}\left[R_D \parallel (R_1+R_2)\right]\right]$$

$$R_{out,closed} = \frac{\left[R_D \parallel (R_1+R_2)\right]}{1+\frac{R_2}{R_1+R_2}\, g_{m1}\left[R_D \parallel (R_1+R_2)\right]}$$

② SHUNT - SERIES FEEDBACK :-

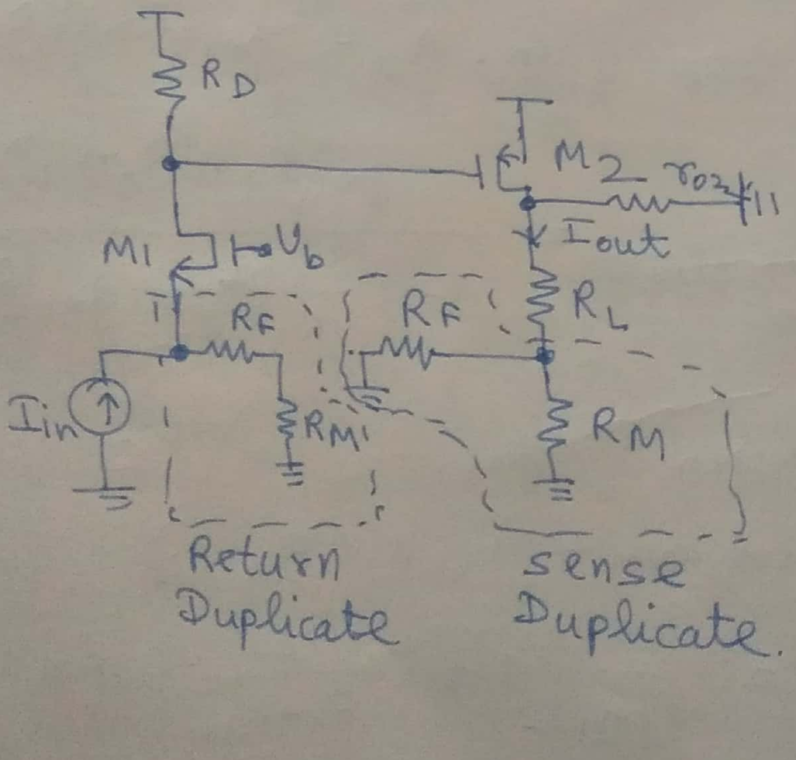


step-1 :- Feedback network comprises of R_F and R_M.

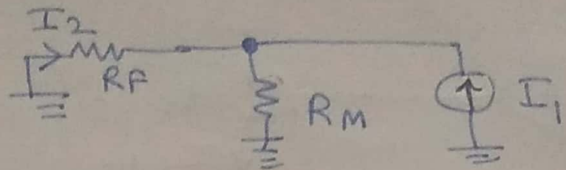
step-2 :- Forward amplifier consists of M_1, R_D and M_2.

step-3 :- The input and output port of β-network are annotated.

step-4 :- Breaking the loop properly, i.e., at o/p of β-NW.



step-5 :- Obtaining β.



$$\beta = -\frac{R_M}{R_F + R_M}$$

step-6 :- obtain open-loop parameters.

$$A_{i,open} = \frac{(R_F + R_M) R_D}{R_F + R_M + \frac{1}{g_{m1}}} \cdot \frac{-g_{m2} r_{o2}}{r_{o2} + R_L + (R_M \| R_F)}$$

$$R_{in,open} = \frac{1}{g_{m1}} \| (R_F + R_M).$$

$$R_{out,open} = r_{o2} + (R_F \| R_M).$$

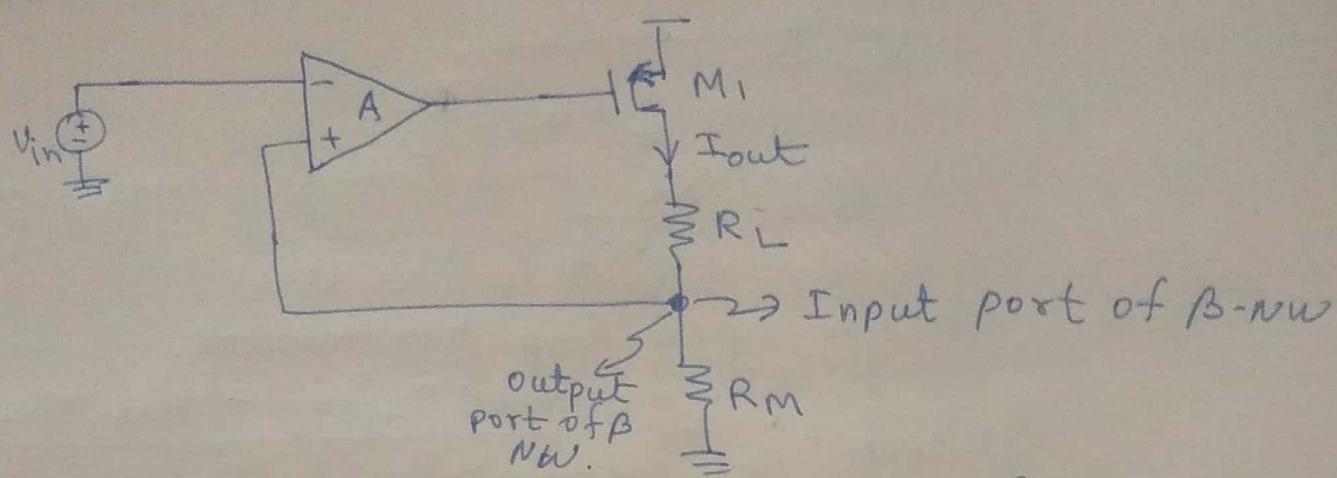
step-7 :-

$$A_{i,closed} = \frac{A_{i,open}}{1 + A_{i,open}\beta}$$

$$R_{in,closed} = \frac{R_{in,open}}{1 + A_{i,open}\beta}.$$

$$R_{out,closed} = R_{out,open}(1 + A_{i,open}\beta).$$

3 SERIES-SERIES FEEDBACK :-

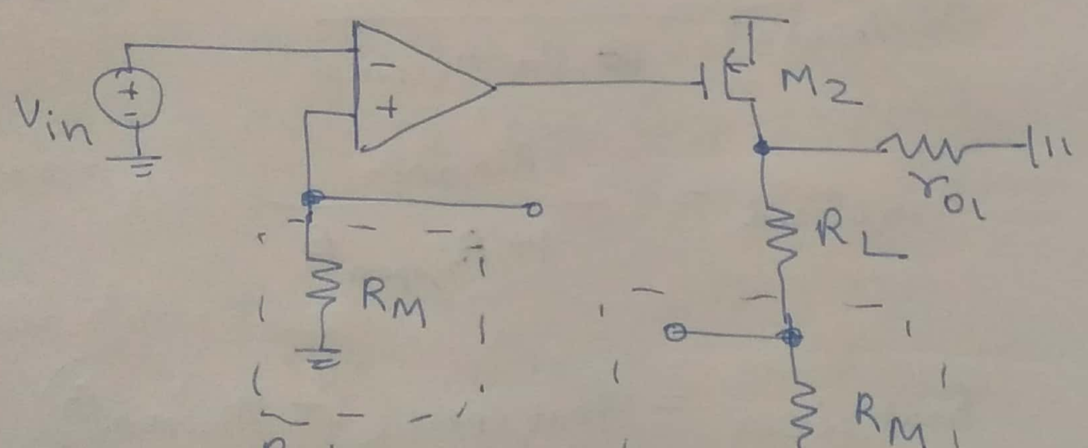


step-1 :- Feedback network comprises of R_M.

step-2 :- Feedforward network comprises of A and M_1.

step-3 :- I/O port of β-NW are annotated.

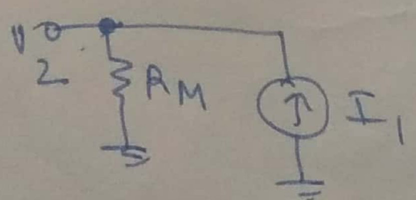
step-4 :- Breaking the loop properly, i.e., at output port of β-NW.



Return Duplicate

sense Duplicate.

step-5 :- Obtaining β



$\beta = R_M$.

Step-6 :- Obtain open loop parameters.

$$G_{m,open} = \frac{g_{m2} A_1 \cdot r_{o1}}{r_{o1} + R_L + R_M}.$$

$$R_{in,open} = \infty$$

$$R_{out,open} = (R_M + r_{o1}).$$

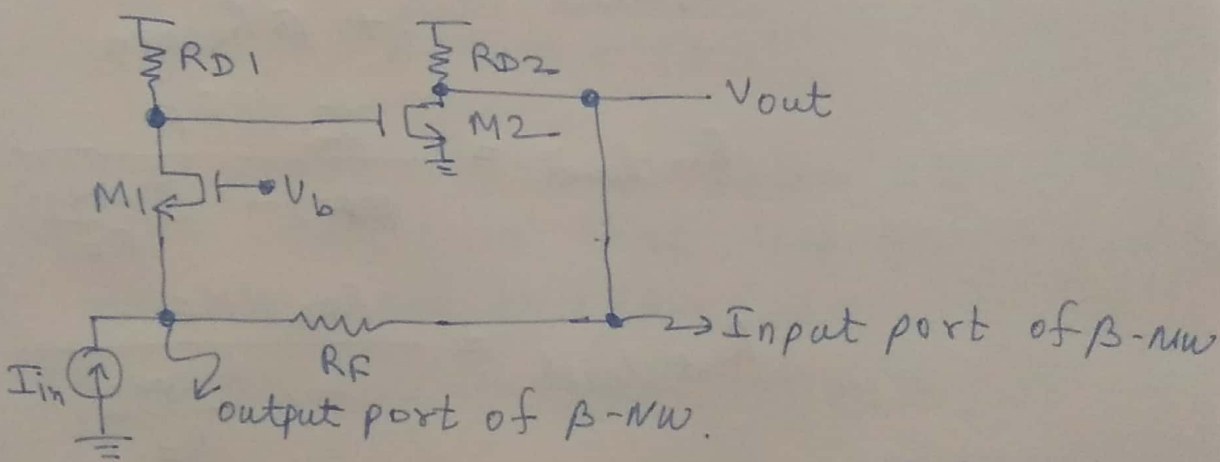
Step-7 :-

$$G_{m,closed} = \frac{G_{m,open}}{1 + G_{m,open}\beta}.$$

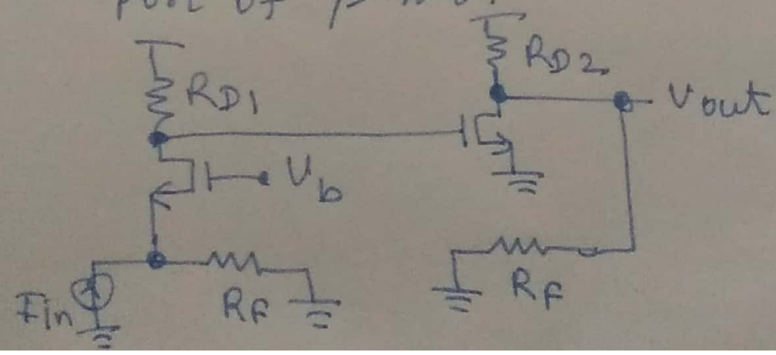
$$R_{in,closed} = \infty$$

$$R_{out,open} = (r_{o1} + R_M)(1 + R_M G_{m,open})$$

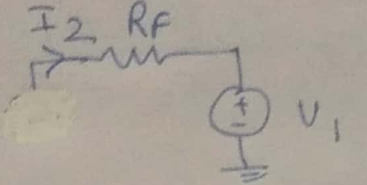
(5) SHUNT - SHUNT FEEDBACK :-



Step-1 :- Feedback network comprises of R_F.
Step-2 :- Forward amplifier comprises of M_1, R_{D1}, M_2 and R_{D2}.
Step-3 :- I/O port of β-NW is annotated.
Step-4 :- Break the loop properly, i.e. at the o/p port of β-NW.



step-5 :- obtaining β.



$$\beta = -\frac{1}{R_F}.$$

step-6 :- obtain open-loop parameters.

$$R_{o,open} = \frac{R_F R_{D1}}{R_F + \frac{1}{g_{m1}}}\left[-g_{m2}\left(R_{D2} \parallel R_F\right)\right]$$

$$R_{in,open} = \frac{1}{g_{m1}} \parallel R_F.$$

$$R_{out,open} = R_{D2} \parallel R_F.$$

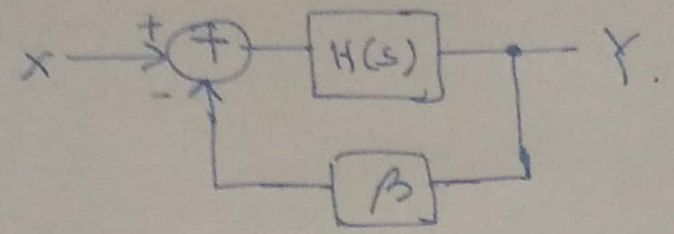
step-7 :-

$$R_{o,closed} = \frac{R_{o,open}}{1 + \beta R_{o,open}}$$

$$R_{in,closed} = \frac{\frac{1}{g_{m1}} \parallel R_F}{1 - \frac{R_{o,open}}{R_F}}$$

$$R_{out,closed} = \frac{R_{D2} \parallel R_F}{1 - \frac{R_{o,open}}{R_F}}.$$

PROBLEM OF INSTABILITY :-



$$\frac{Y}{X}(s) = \frac{H(s)}{1+\beta H(s)}.$$

If $\beta H(s)$ or loop gain has a value of -1 at particular frequency ω_1, then $\frac{Y}{X}(s) \to \infty$ resulting in oscillation.

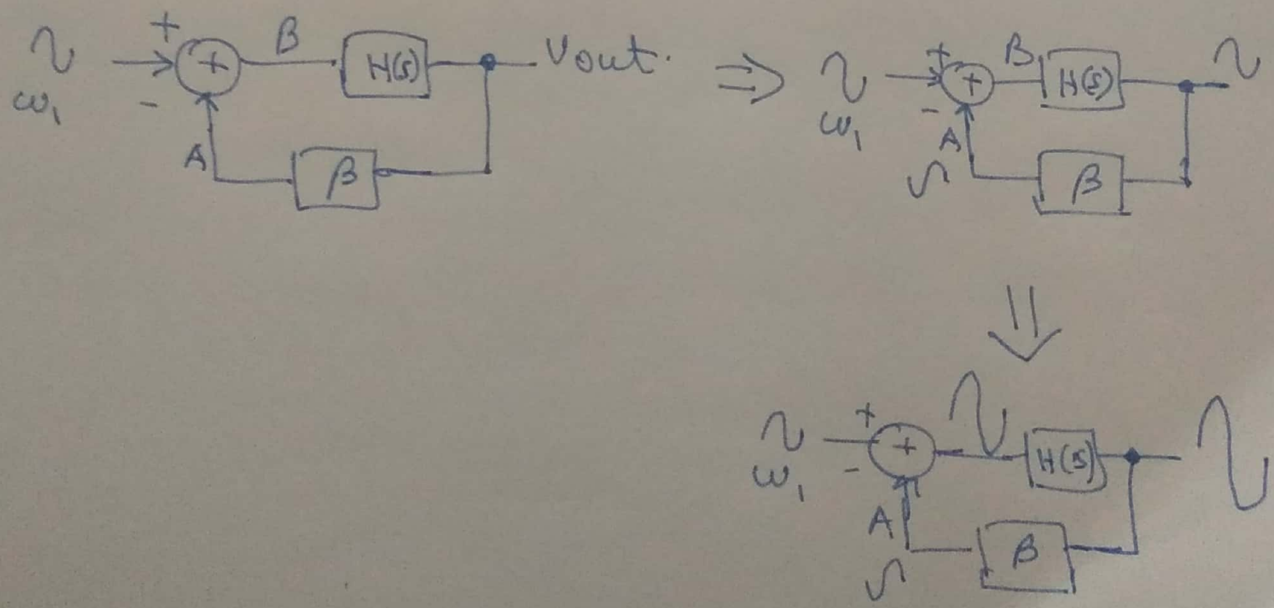
Barkhausen's Criteria For Oscillation :-

$$|\beta H(j\omega_1)| = 1$$

$$\angle \beta H(j\omega_1) = -180^\circ.$$

* So to make the closed-loop system stable we have to make sure that loop-gain < 1 when the loop-phase is 180°.

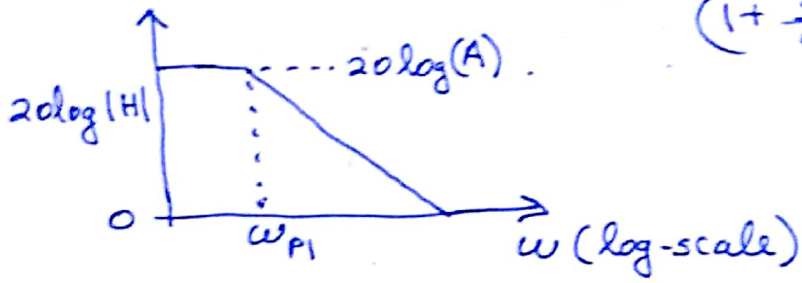
Onset of Oscillation in slow Motion :-

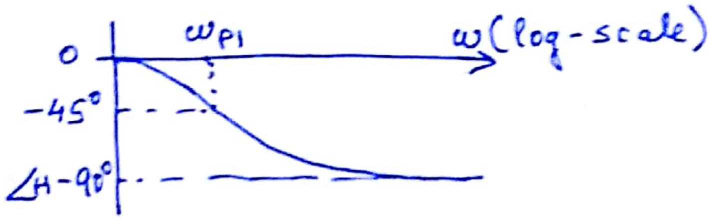


(24) **BODE PLOT REVIEW**

① **1-Pole system:-**

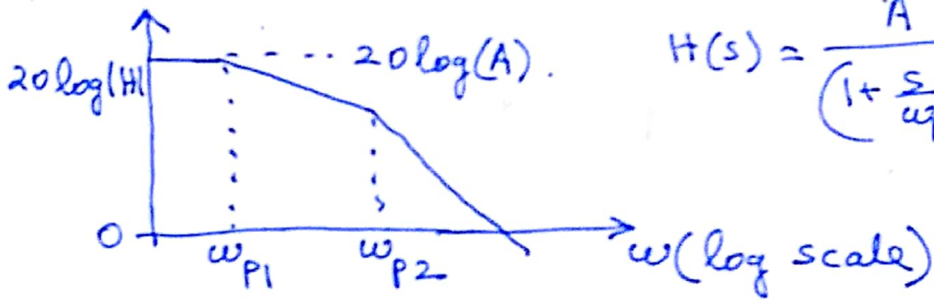
$$H(s) = \frac{A}{\left(1+\frac{s}{\omega_{P1}}\right)}$$

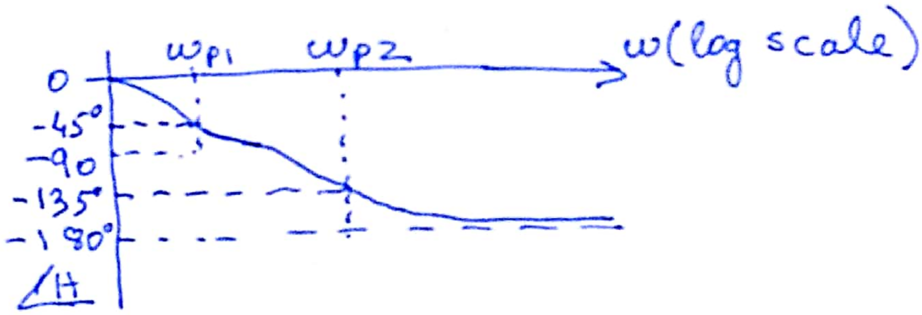




② **2-Pole system:-**

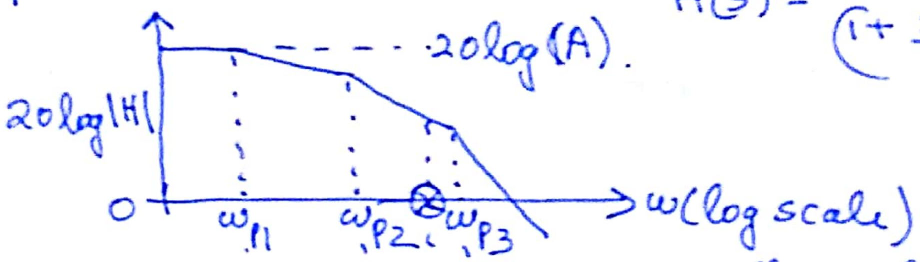
$$H(s) = \frac{A}{\left(1+\frac{s}{\omega_{P1}}\right)\left(1+\frac{s}{\omega_{P2}}\right)}$$

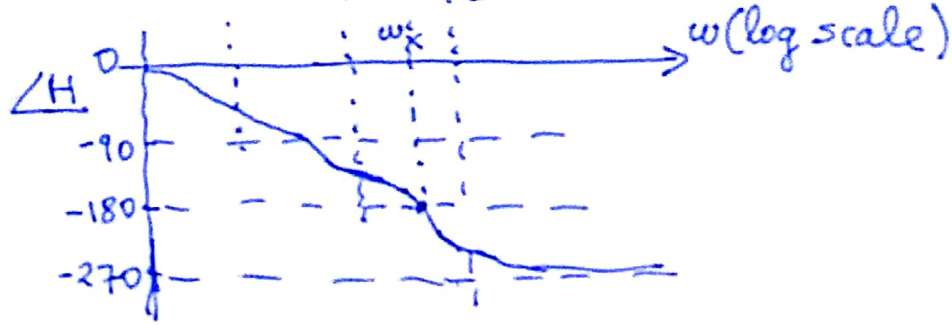




③ **3-pole system:-**

$$H(s) = \frac{A}{\left(1+\frac{s}{\omega_{P1}}\right)\left(1+\frac{s}{\omega_{P2}}\right)\left(1+\frac{s}{\omega_{P3}}\right)}$$





* As can be clearly seen for a 3-pole system the phase hits $180°$ at ω_x and gain > 1.
* So, if we put feedback around that system there could be oscillation.
* In a negative feedback system as mentioned earlier if the following condition is satisfied then oscillation happens at ω_1.

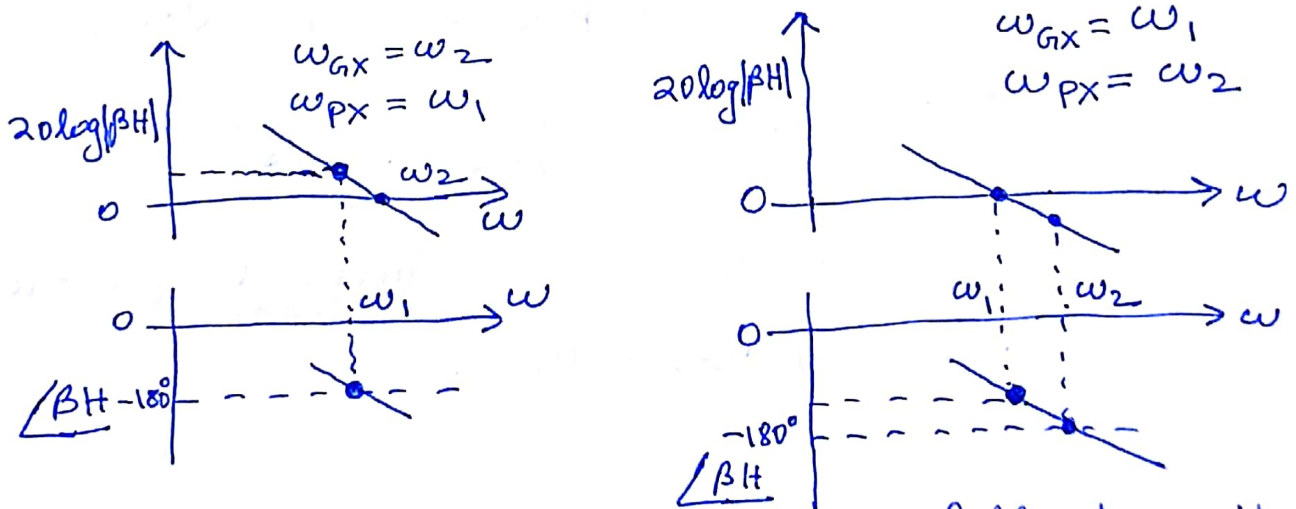
$$|\beta H(j\omega_1)| = 1$$

$$\angle \beta H(j\omega_1) = -180°$$

* If $|\beta H(j\omega)| < 1$ then the output cannot grow indefinitely.

STABILITY CONDITION:-

* If $|\beta H(j\omega_1)| > 1$ and $\angle \beta H(j\omega_1) = -180°$ the negative feedback system oscillates.
* To avoid this we have to make sure that both the gain and phase conditions do not get satisfied at any frequency.



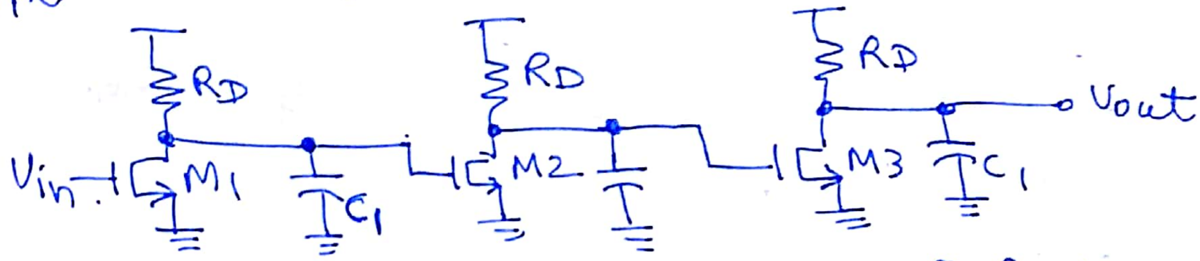
* Frequency at which the loop-gain falls to unity is called gain crossover frequency, ω_{GX}.
* Frequency at which phase reaches $-180°$ is called phase crossover frequency, ω_{PX}.

* In the above example ω_{Gx} and ω_{px} are annotated. Based on that we conclude that a negative-feedback system would be stable if,

$$\omega_{Gx} < \omega_{px}.$$

and is called stability criteria based on Bode-Plot ⇒ Guaranteen that "Barkhausen's Criteria" is not satisfied at any frequency.

Example:-



If we put negative feedback with $\beta = 1$ in the above circuit derive the condition of stability. Assume $\lambda = 0$, M_1, M_2 and M_3 are identical and ignore parasitic capacitances.

Ans:-

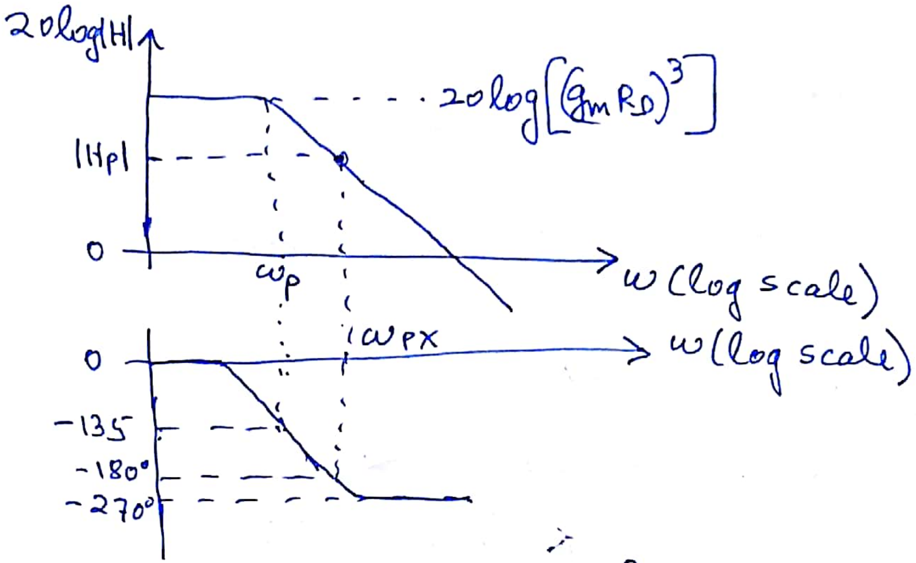
Low frequency gain $= (g_m R_D)^3$.

Each stage has a pole at $\omega_{p1} = (R_D C_1)^{-1}$.

Thus,
$$H(s) = \frac{(g_m R_D)^3}{\left(1 + \frac{s}{\omega_p}\right)^3}$$

and $\beta = 1$ ... as given in question.

There loop gain $= \beta H(s) = H(s)$.



At, ω_{px} the phase is $-180°$.

Thus,

$$-3\tan^{-1}\left(\frac{\omega_{px}}{\omega_p}\right) = -180°$$

$$\Rightarrow \quad \omega_{px} = \sqrt{3}\,\omega_p .$$

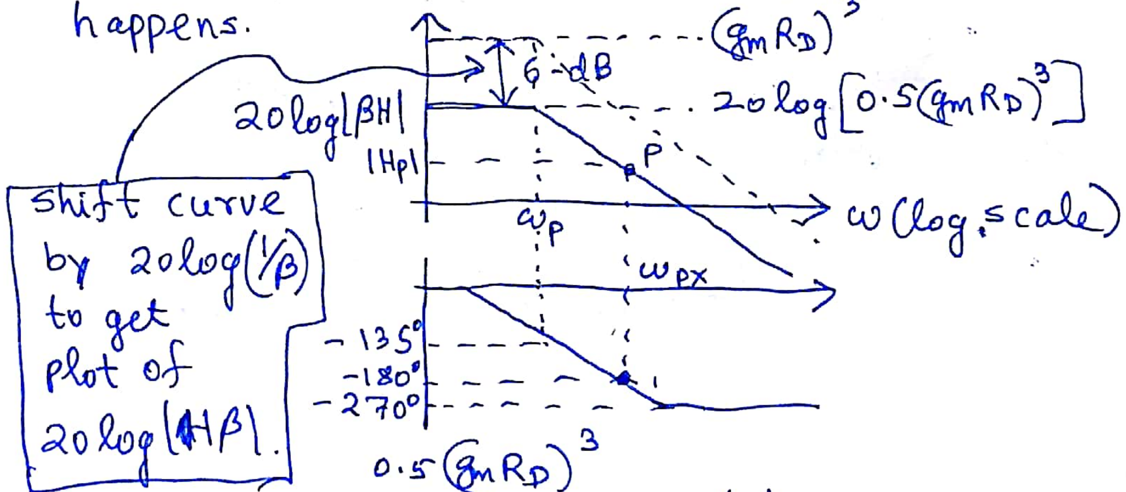
At ω_{px} the ~~gain~~ loop-gain < 1. Thus,

$$\frac{(g_m R_D)^3}{\left[\sqrt{1+\left(\frac{\omega_{px}}{\omega_p}\right)^2}\,\right]^3} < 1$$

$$\Rightarrow \quad g_m R_D < 2 .$$

If $g_m R_D$ exceeds 2 then oscillation can set-in.

* In the above example if $\beta = 0.5$ what happens.



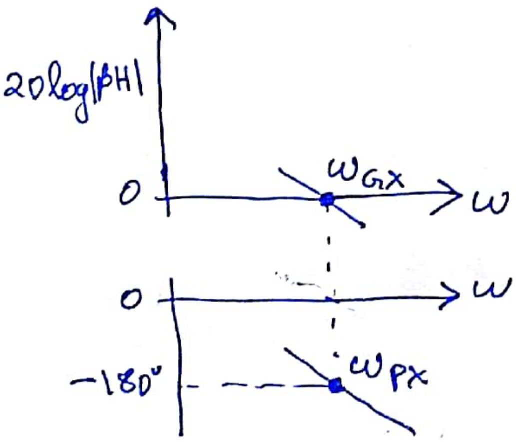
$$\frac{0.5\,(g_m R_D)^3}{\left[\sqrt{\left(1+\left(\frac{\omega_{px}}{\omega_p}\right)^2\right)}\,\right]^3} < 1$$

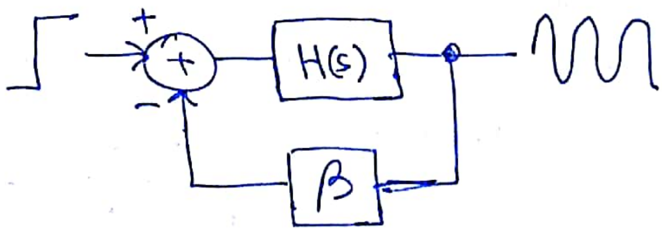
Thus, $(g_m R_D)^3 < \frac{2^3}{0.5}$

* Hence, weaker feedback allows greater open-loop gain.

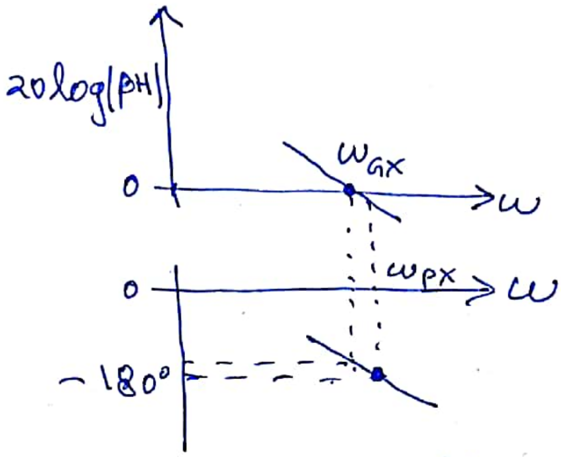
SOME KEY OBSERVATIONS :-

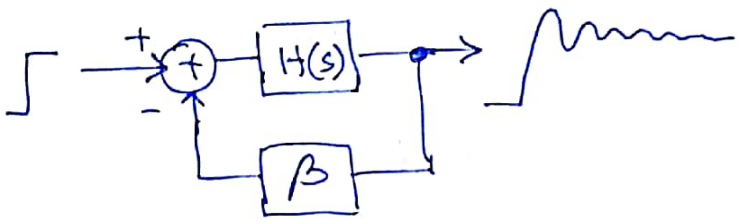
1. Feedback factor $\beta \leq 1$, with $\beta = 1$ called unity-feedback, i.e., strongest amount of feedback.
2. ~~Since~~ Changing the feedback factor translates the gain plot (Bode) ~~up and~~ down.
3. Changing feedback factor does not alter the phase-plot (Bode) much.
4. If a system can be made stable with $\beta = 1$, then the system is guaranteed to be stable for any β.



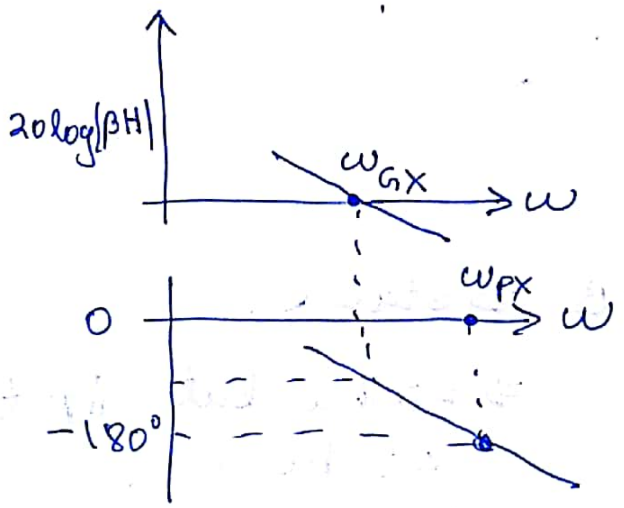


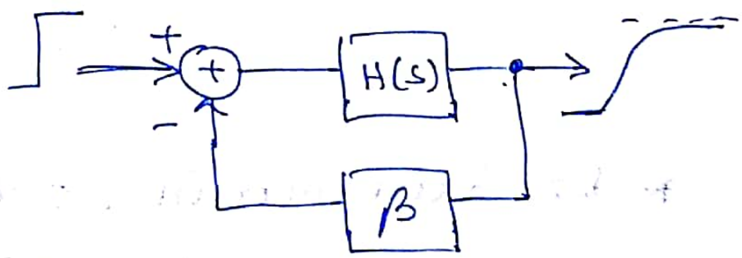
$\omega_{GX} = \omega_{PX} \Rightarrow$ Oscillatory.





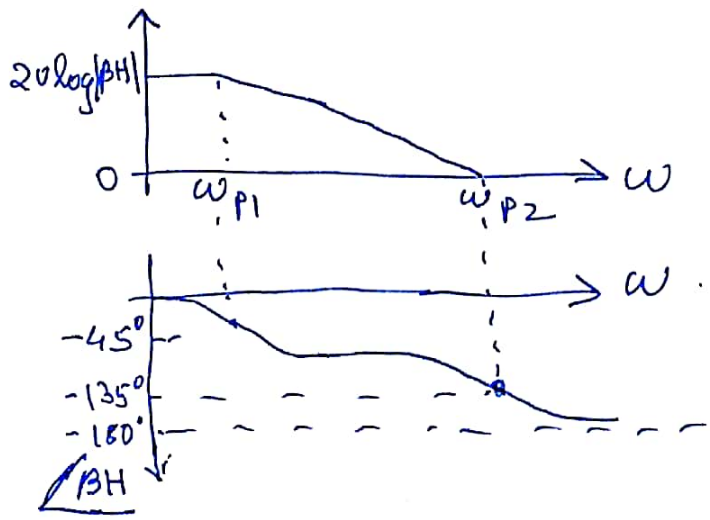
ω_{GX} is slightly below ω_{PX}.





ω_{GX} is well below ω_{PX}

PHASE MARGIN = $\angle \beta H(\omega_{GX}) + 180^\circ$.

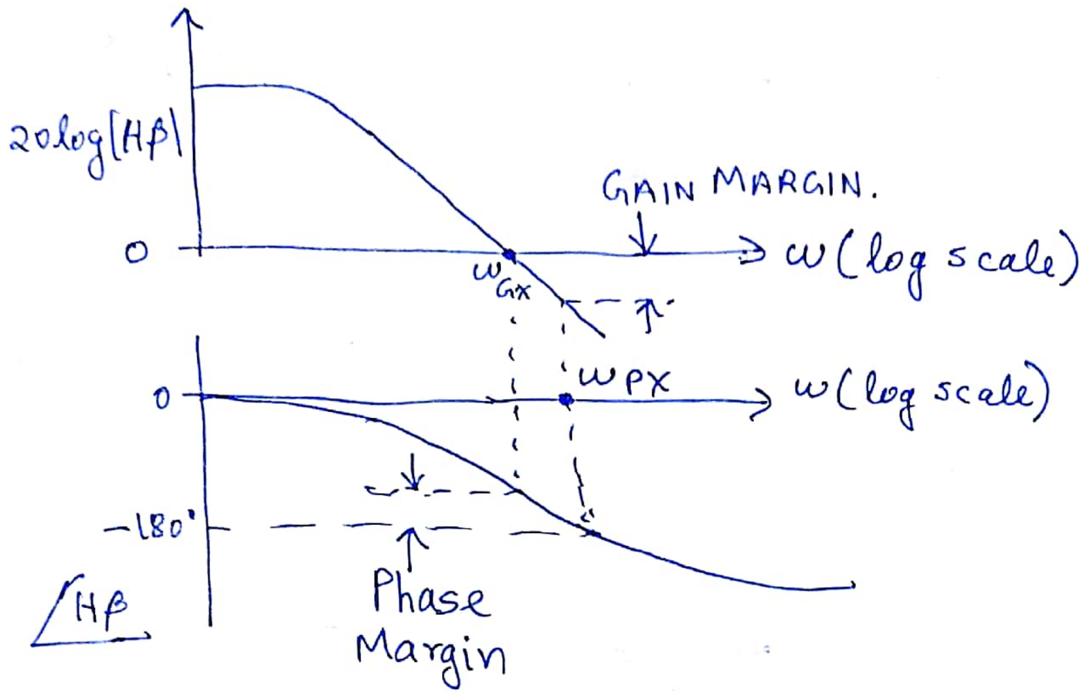


Phase margin = 45°.

* For well behaved system typical Phase Margin required is 60°.

30

GAIN MARGIN $= |\beta H|_{\omega_{px}}$



* If Gain-margin < 0 dB ⇒ stable.

  If Phase-margin > 0° ⇒ stable but might not be well behaved.

  Phase-margin > 60° ⇒ stable & well behaved.

Example 1:- one-pole open-loop transfer function is given by,

$$H(s) = \frac{A_0}{1+\frac{s}{\omega_0}}.$$

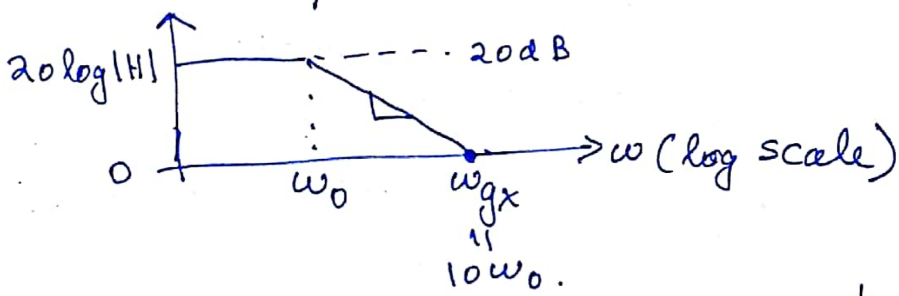
what is the phase-margin if $\beta = 1$.

Ans:- A single pole system rolls of at a rate of $-20\,dB/dec$ in case of Bode-Gain Plot.

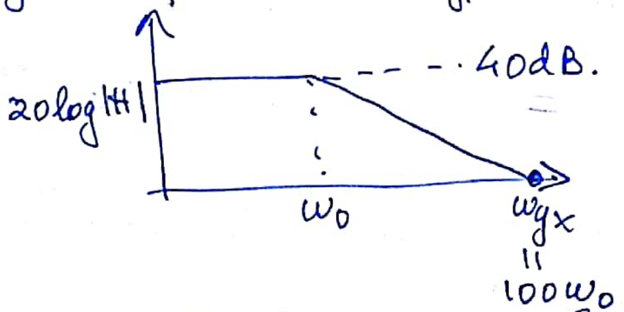
DC gain $= 20\log(A_0)$ dB.

ω_{gx} = gain-cross over frequency is $10^{(\log A_0)}$ decades away from ω_0.

For example if $20\log A_0 = 20\,dB$ then ω_{gx} is 1 decade away from ω_0 as shown below:-



If $20\log A_0 = 40\,dB$ then $\omega_{gx} = 100\,\omega_0$ as shown below.



If $20\log A_0 = 30\,dB$ then $\omega_{gx} = 10^{(30/20)}\omega_0 = 31.62\,\omega_0$.

Thus, phase at ω_{gx} is given by,

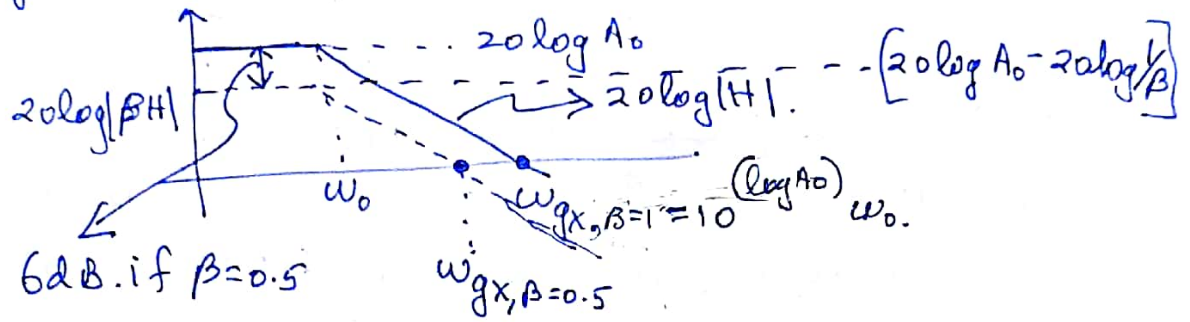
$$\angle H(\omega_{gx}) = -\tan^{-1}\left[\frac{10^{(\log A_0)}\omega_0}{\omega_0}\right]$$

$$\Rightarrow \angle H(\omega_{gx}) = -\tan^{-1}\left[10^{\log A_0}\right].$$

Therefore, Phase Margin $= 180^\circ - \tan^{-1}\left[10^{\log A_0}\right]$ if $\beta = 1$

(32)

* What if $\beta = 0.5$ then the loop gain Bode-plot is going to look as follows:-



Now, $\omega_{g.x,\beta=1} = 10^{(\log A_0)}\,\omega_0.$

$$\omega_{gx,\beta} = 10^{[\log A_0 - \log(1/\beta)]}\,\omega_0.$$

Hence, for $\beta=0.5$ we get,

$$\omega_{gx,\beta=0.5} = 10^{[\log A_0 - 0.3]}\,\omega_0.$$

$$\Rightarrow \omega_{gx,\beta=0.5} = 0.5\,10^{\log A_0}\,\omega_0.$$

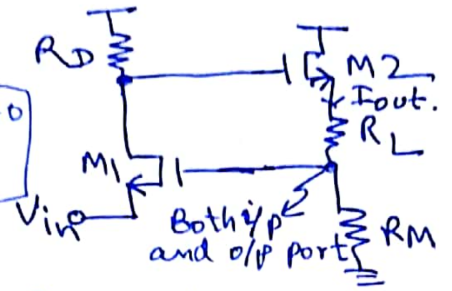
$$\Rightarrow \omega_{gx,\beta=0.5} = 0.5\,\omega_{gx,\beta=1}.$$

$$\therefore \text{Phase Margin} = 180° - \tan^{-1}\left[0.5 * 10^{(\log A_0)}\right].$$

* Thus, as feedback factor reduces the phase margin increases.

Example-2:-

Assume $\lambda = 0$ for M_1 and M_2,



(i) What is the kind of feedback?

(ii) Derive various parameters like $R_{in,closed}$, $R_{out,closed}$ and $G_{m,closed}$.

* sensing Current. ⇒ series sampling
* Returning Voltage ⇒ series mixing.

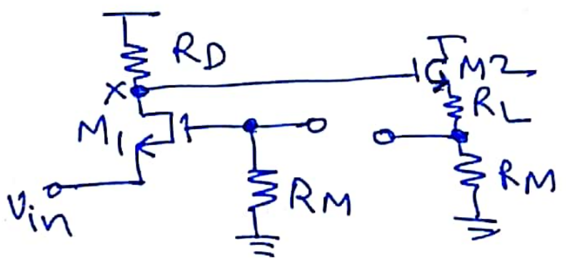
Thus, series-series feedback or current-voltage feedback

step-1:- Feedback network comprises of R_M.

step-2:- Forward amplifier consists of M_1, R_D, and M_2.

step-3:- The input and output port of feedback network is annotated.

step 4:- Break the loop properly.



step 5:- Compute β.

$\Rightarrow \beta = R_M$.

step 6:- Open loop gain is,

$$G_{m,open\text{-}loop} = \left(\frac{V_X}{V_{in}}\right)\cdot\left(\frac{I_{out}}{V_X}\right)$$

Let, source of M_2 be called node "A". Thus,

$$\frac{V_A}{V_X} = \frac{R_L + R_M}{R_L + R_M + \frac{1}{g_{m2}}}.$$

Thus, $I_{out} = \dfrac{V_A}{R_L + R_M} = \dfrac{V_X}{R_L + R_M + \frac{1}{g_{m2}}}$.

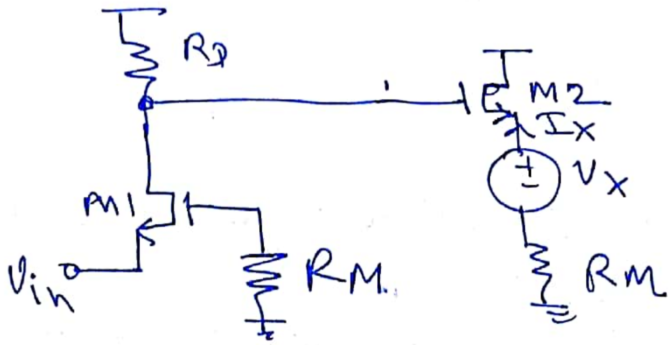
34

Hence,

$$G_{m,\text{open-loop}} = \frac{g_{m1} R_D}{R_L + R_M + \frac{1}{g_{m2}}}.$$

$$R_{in,\text{open-loop}} = 1/g_{m1}$$

To find $R_{out,\text{open-loop}}$ we apply the test voltage V_x as shown below and measure I_x.



Thus, $R_{out,\text{open-loop}} = \frac{1}{g_{m2}} + R_M.$

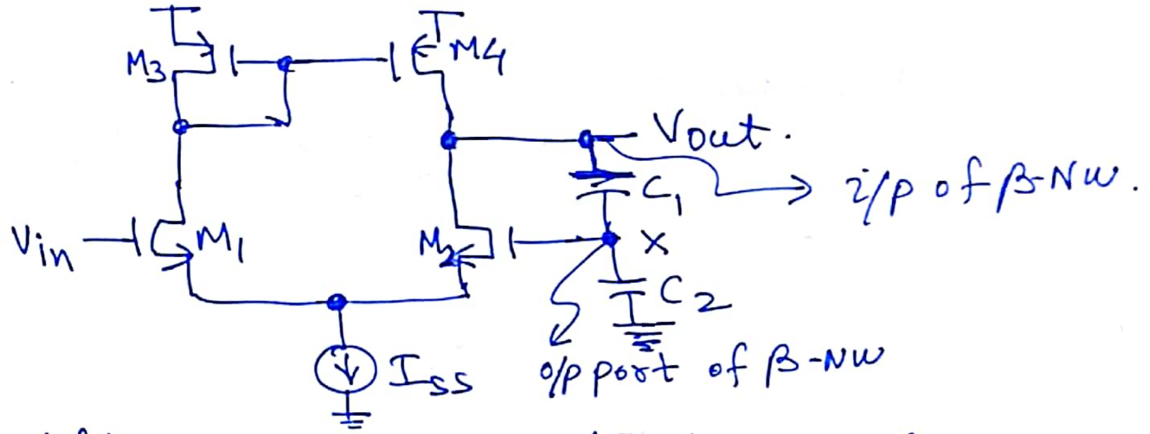
Step 7:-

$$G_{m,\text{closed-loop}} = \frac{G_{m,\text{open-loop}}}{1 + R_M G_{m,\text{open-loop}}}$$

$$R_{in,\text{closed}} = \frac{1}{g_{m1}}(1 + R_M G_m)$$

$$R_{out\ \text{closed}} = \left(\frac{1}{g_{m2}} + R_M\right)(1 + R_M G_m).$$

Example 3:- Identify the type of feedback in the following circuit. At low frequencies, is there any loading effect? Compute the loop gain and the closed loop gain, input-impedance, and output impedance.



Ans:- Voltage sensing ⇒ shunt sampling.
Voltage mixing ⇒ series mixing.

series-shunt feedback
or.
voltage-voltage feedback.

* C_1 and C_2 comprise the feedback network.
* At low frequencies current through feedback network is negligible ⇒ no-loading effect
* V_X is fedback and it is a fraction of output voltage. Thus,

$$\beta = \frac{V_X}{V_{out}} = \frac{C_1}{C_1+C_2}.$$

* when there is no loading effect you can break the loop ~~anywhere~~ either at the i/p port or o/p port of β-network.
* Forward path consists of $M_1, M_2, M_3,$ and M_4. having a voltage gain of, $A_v = g_m(r_{o2} \| r_{o4})$

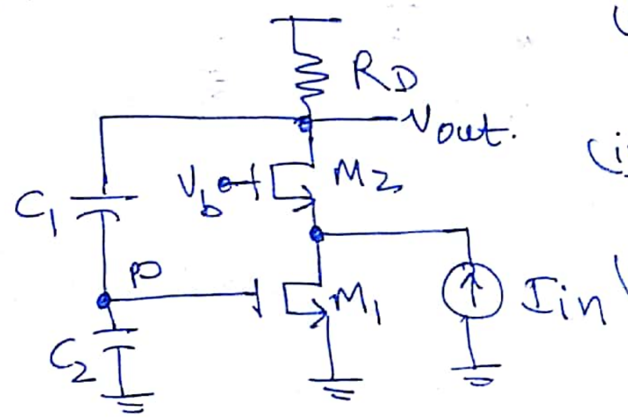
(36) Thus, $$A_{closed} = \frac{g_m (r_{o2} \| r_{o4})}{1 + \frac{C_1}{C_1 + C_2} g_m (r_{o2} \| r_{o4})}$$

where, $g_m = g_{m1} = g_{m2}$.

* $R_{out,open} = (r_{o2} \| r_{o4})$.

$$\Rightarrow R_{out, closed} = \frac{r_{o2} \| r_{o4}}{1 + \frac{C_1}{C_1 + C_2} g_m (r_{o2} \| r_{o4})}.$$

Example 4 :-



(i) Identify the type of feedback.
(ii) Is there loading effect at low freq.
(iii) Comput closed loop-gain, R_{in},closed-loop, and R_{out}, closed-loop.

* Assume $\lambda = 0$.

Ans :- V_{out} is sensed $\Rightarrow$ shunt-sampling.
Part of V_{out} shows up at V_P modulating the V_{GS} of M_1 thus subtracting current from I_{in}.
Hence, Current mixing $\Rightarrow$ shunt-mixing.

Thus, shunt-shunt feedback. or voltage-current feedback.

* At low frequency the feedback network C_1 and C_2 ~~are open~~ do not draw current from output. $\Rightarrow$ No loading effect.
* Forward amplifier comprises of M_2 and R_D.
* Feedback network includes C_1, C_2 and M_1.

Thus, $$\beta = \frac{C_1}{C_1 + C_2} g_{m1}.$$

and, $$R_{open} = \frac{V_{out}}{I_{in}} = R_D.$$

resulting in,
$$R_{closed} = \frac{R_D}{1 + \frac{C_1}{C_1+C_2} g_{m1} R_D}.$$

Now, $$R_{in,open} = \frac{1}{g_{m2}}.$$

and, $$R_{out,open} = R_D.$$

Thus,
$$R_{in,closed\text{-}loop} = \frac{1}{g_{m2}} \frac{1}{1 + \frac{C_1}{C_1+C_2} g_{m1} R_D}$$

and, $$R_{out,closed\text{-}loop} = \frac{R_D}{1 + \frac{C_1}{C_1+C_2} g_{m1} R_D}.$$